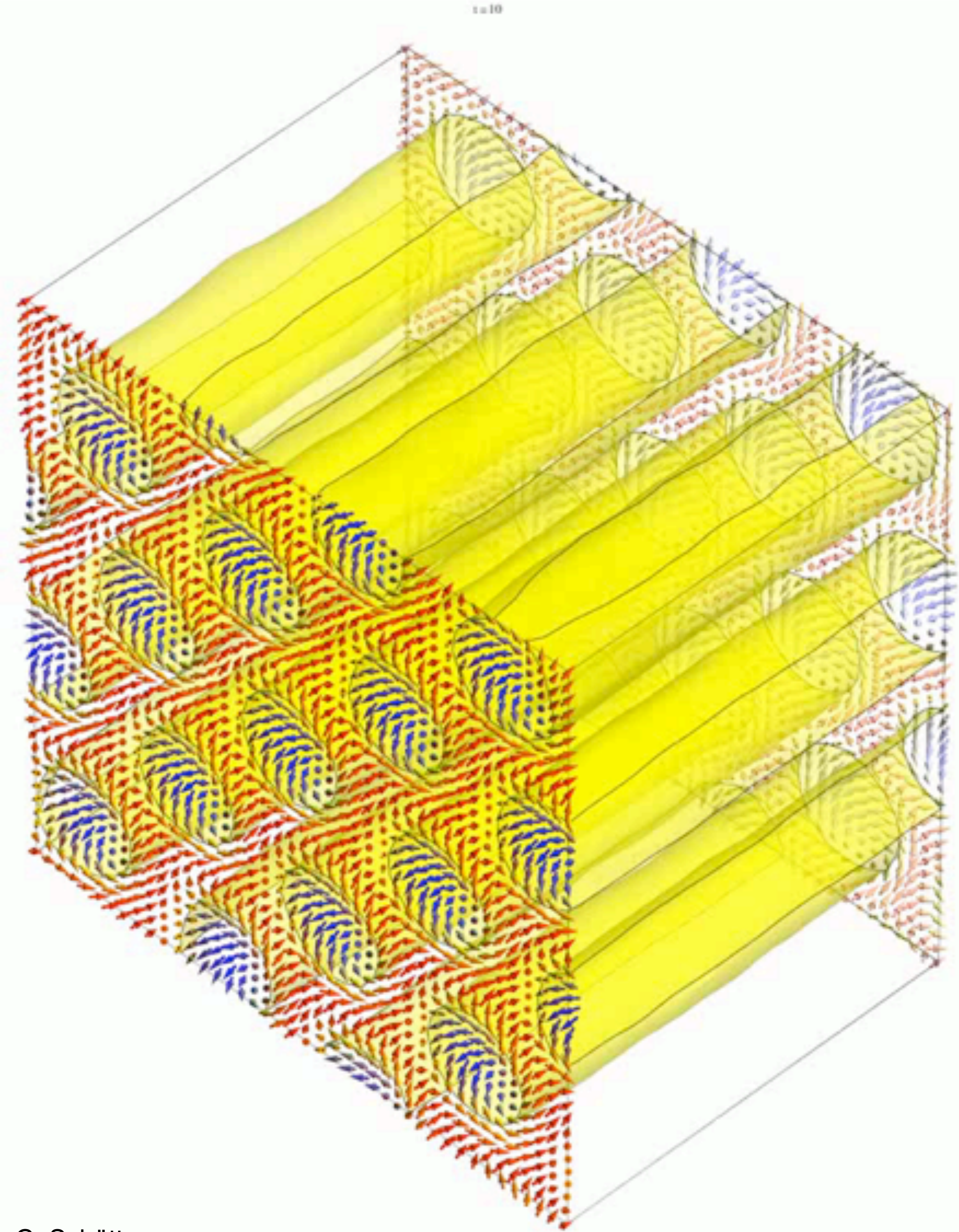


animation C. Schütte

Emergence, Stability and Decay of Skyrmions in Chiral Magnets

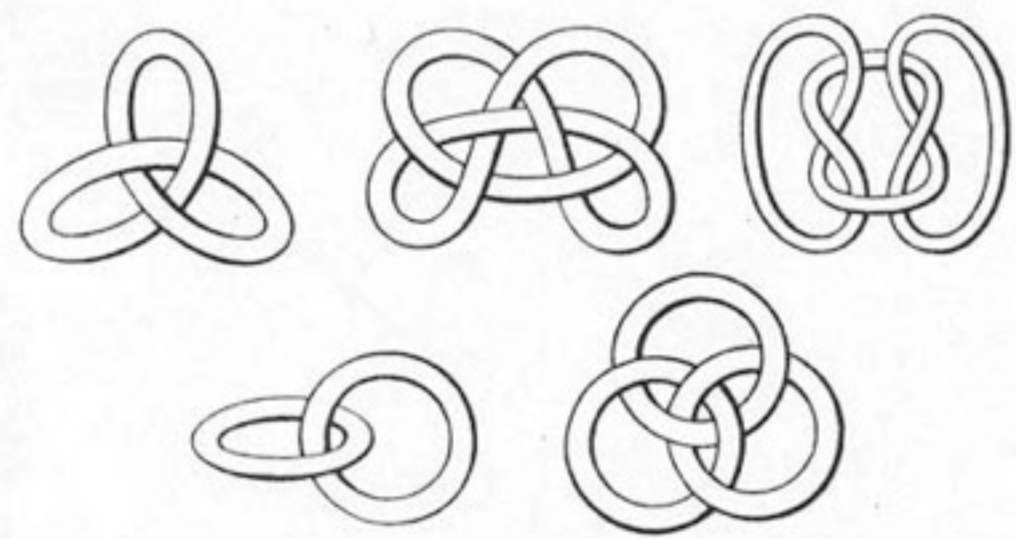
Christian Pfleiderer

Physik-Department
Technische Universität München

Vortices in Daily Life...

Kelvin‘s Vortex Model of Atoms

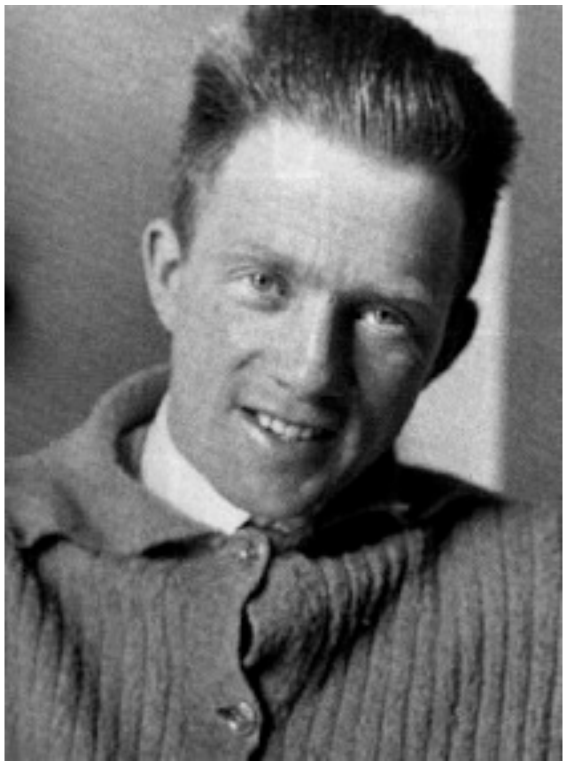
Lord Kelvin
William Thomson
(1824-1907)



Instalment, received Nov.—Dec. 1869 [§ 59—§ 64 (*f*)].

perhaps the first suggestion of
„topological solitons“

Towards a Unified Field Theory



Werner Heisenberg (1901-1976)
NP 1932

key idea:
Are bosons non-linear excitations of fermion fields?

(Are bosons topological solitons of fermion fields?)

RMP **29** 296 (1957)

From Tony Hilton Royle Skyrme to Skyrmions

Tony Skyrme (1922-1987)

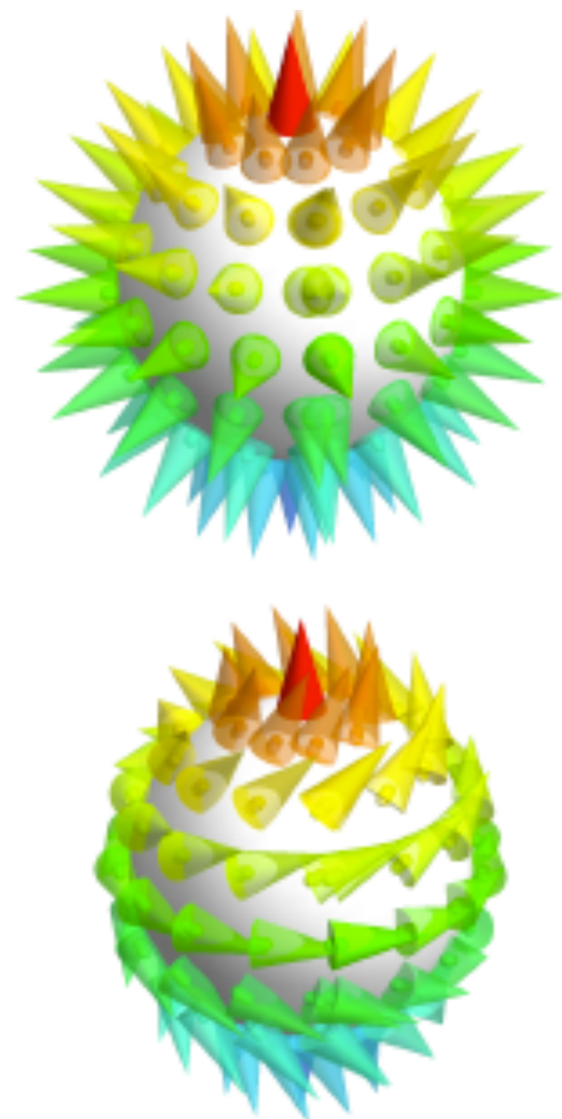
key idea:
Are fermions non-linear excitations of boson fields?

(Are fermions topological solitons of boson fields?
winding number → baryon number)

Proc. Royal Society London, Series A **260**, 130 (1961)
Proc. Royal Society London, Series A **262**, 237 (1961)
Nuclear Physics **31** 556 (1962)

From Tony Hilton Royle Skyrme to Skyrmions

Tony Skyrme (1922-1987)



Proc. Royal Society London, Series A **260**, 130 (1961)
Proc. Royal Society London, Series A **262**, 237 (1961)
Nuclear Physics **31** 556 (1962)

Merriam-Webster OnLine

Merriam-Webster FOR KIDS | Encyclopædia BRITANNICA | Merriam-Webster ONLINE | Merriam-Webster COLLEGIATE® | Merriam-Webster UNABRIDGED

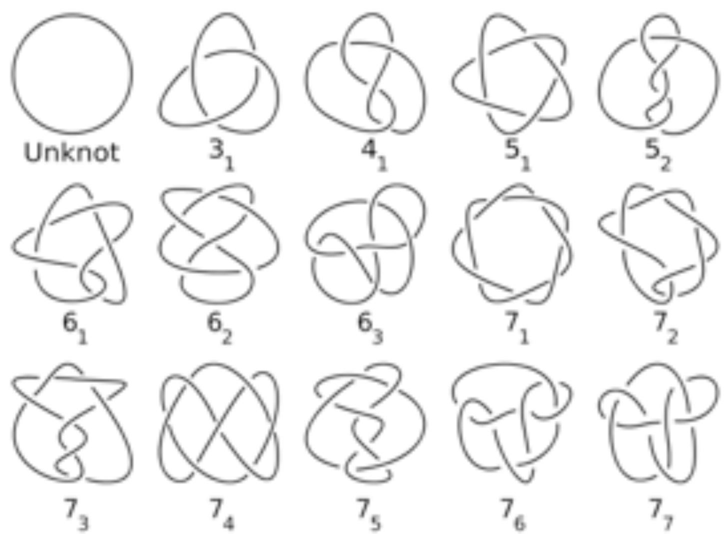
Main Entry: **sol·i·ton**

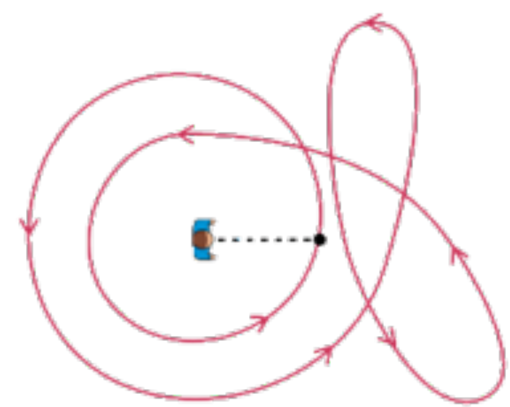
Pronunciation: \ˈsä-lə-ˌtän\

: a solitary wave (as in a gaseous plasma) that propagates with little loss of energy and retains its shape and speed after colliding with another such wave

Main Entry: **to·pol·o·gy**
Pronunciation: \tə-ˈpä-lə-jē, tä-\

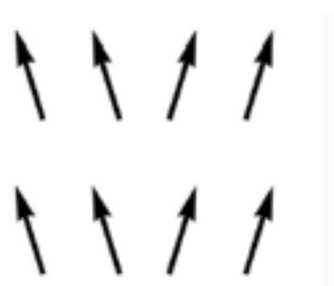
2 a (1) : a branch of mathematics concerned with those properties of geometric configurations (as point sets) which are unaltered by elastic deformations (as a stretching or a twisting) that are homeomorphisms (2) : the set of all open subsets of a topological space **b** : CONFIGURATION <topology of a molecule> <topology of a magnetic field>
— **to·pol·o·gist** \-jist\ *noun*

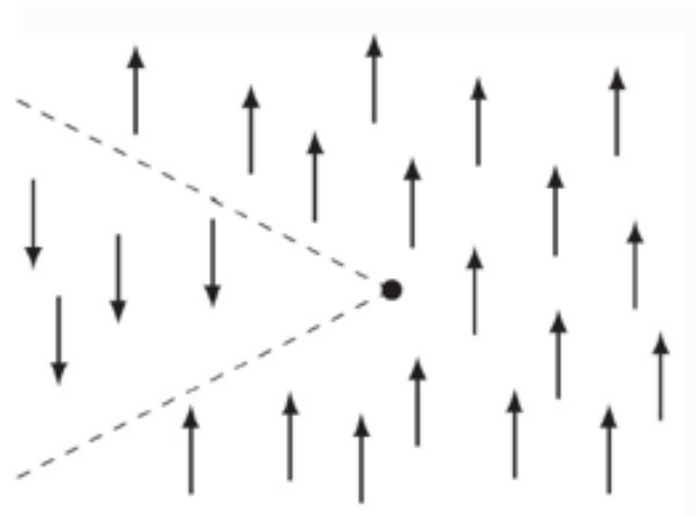


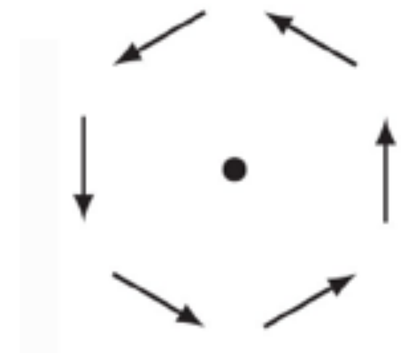


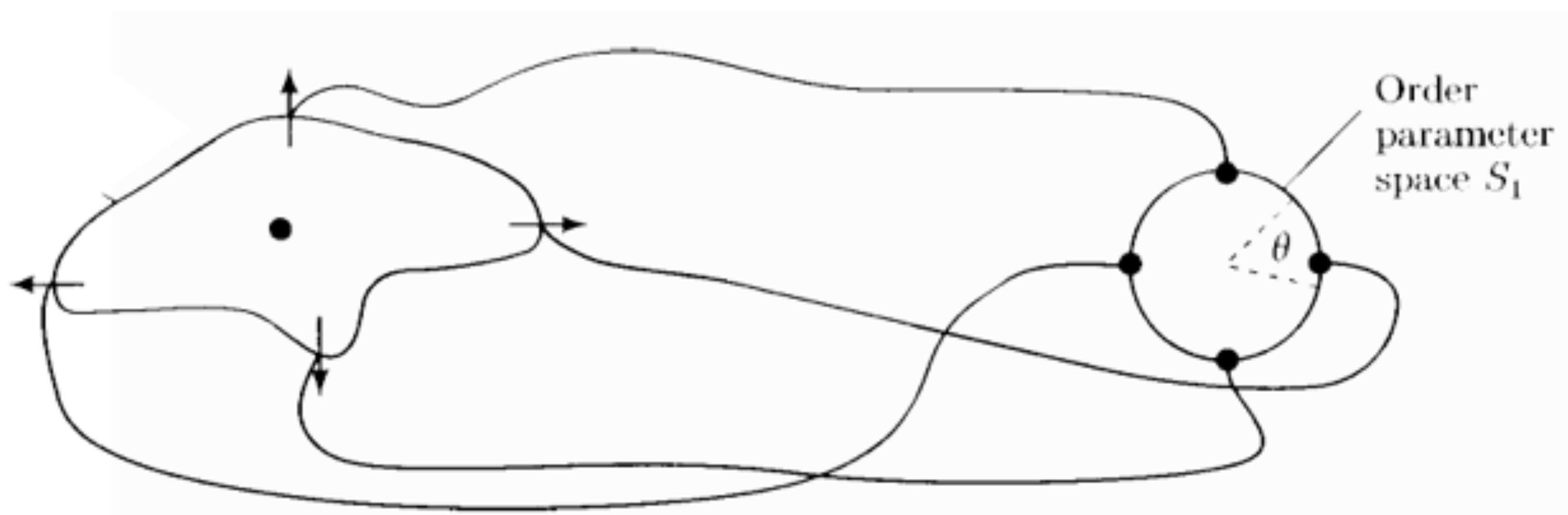
winding number: +2

On the Winding Number in Spin Systems





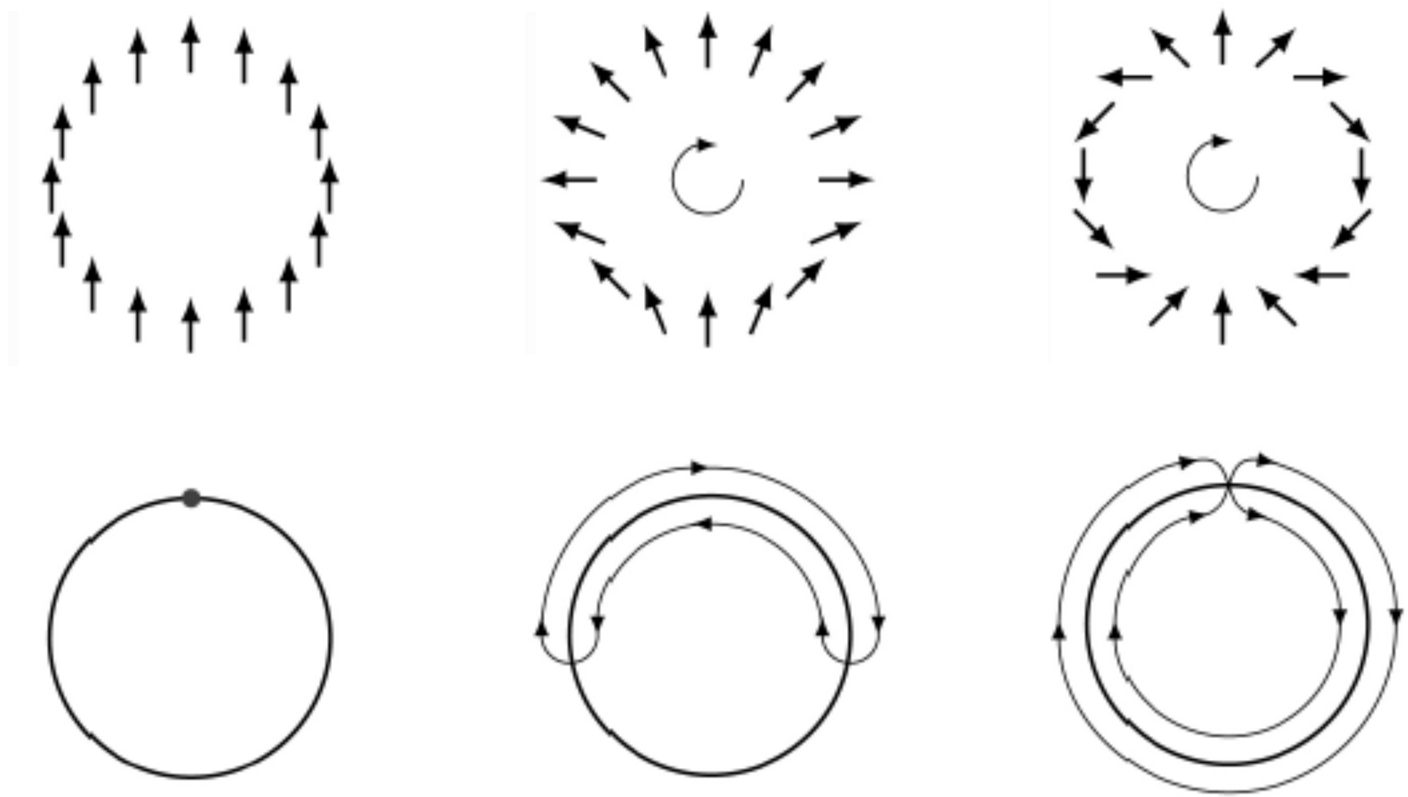




On the Winding Number in Spin Systems

real space

OP space

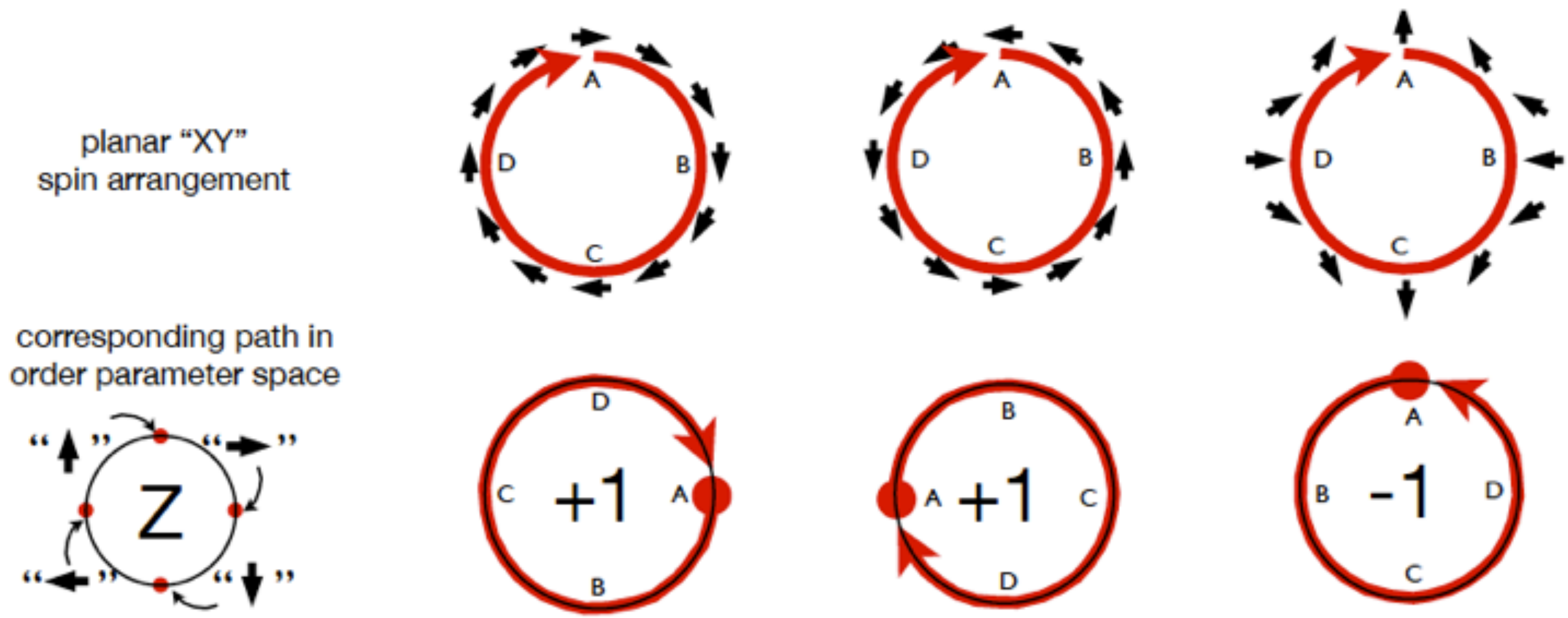


$$\gamma = \frac{1}{2\pi} \oint_\Gamma \nabla \varphi \cdot d\boldsymbol{l}$$

$\nabla \varphi > 0$ if one rotates to the left

$\nabla \varphi < 0$ if one rotates to the right

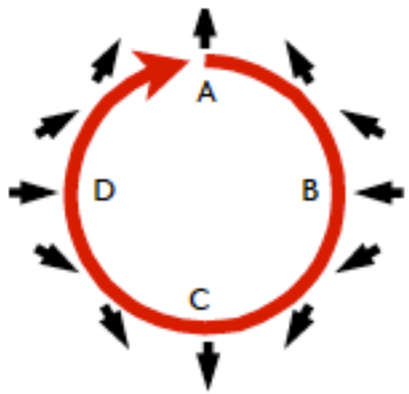
On the Winding Number in Spin Systems

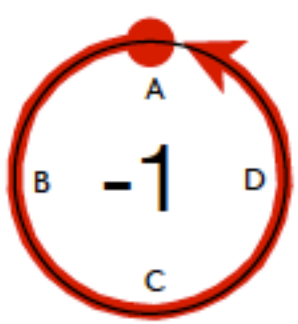


plot M. Rahn

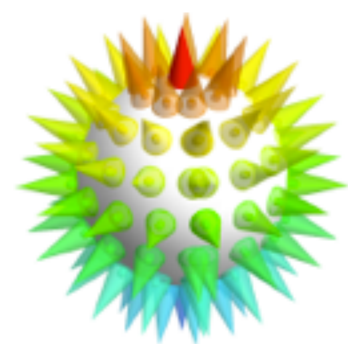
$$\gamma = \frac{1}{2\pi} \oint_{\Gamma} \nabla \varphi \cdot d\boldsymbol{l} \quad \begin{cases} \nabla \varphi > 0 & \text{if one rotates to the left} \\ \nabla \varphi < 0 & \text{if one rotates to the right} \end{cases}$$

Winding in Two-Dimensional OP-Space

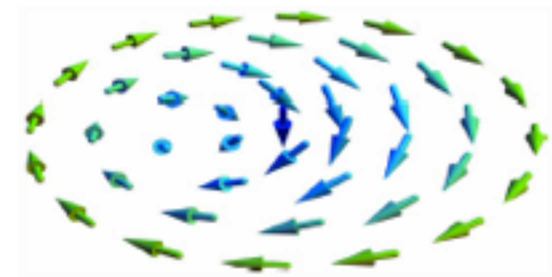


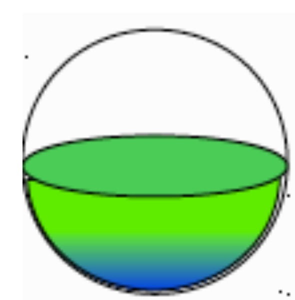


skyrmion



(trivial) vortex

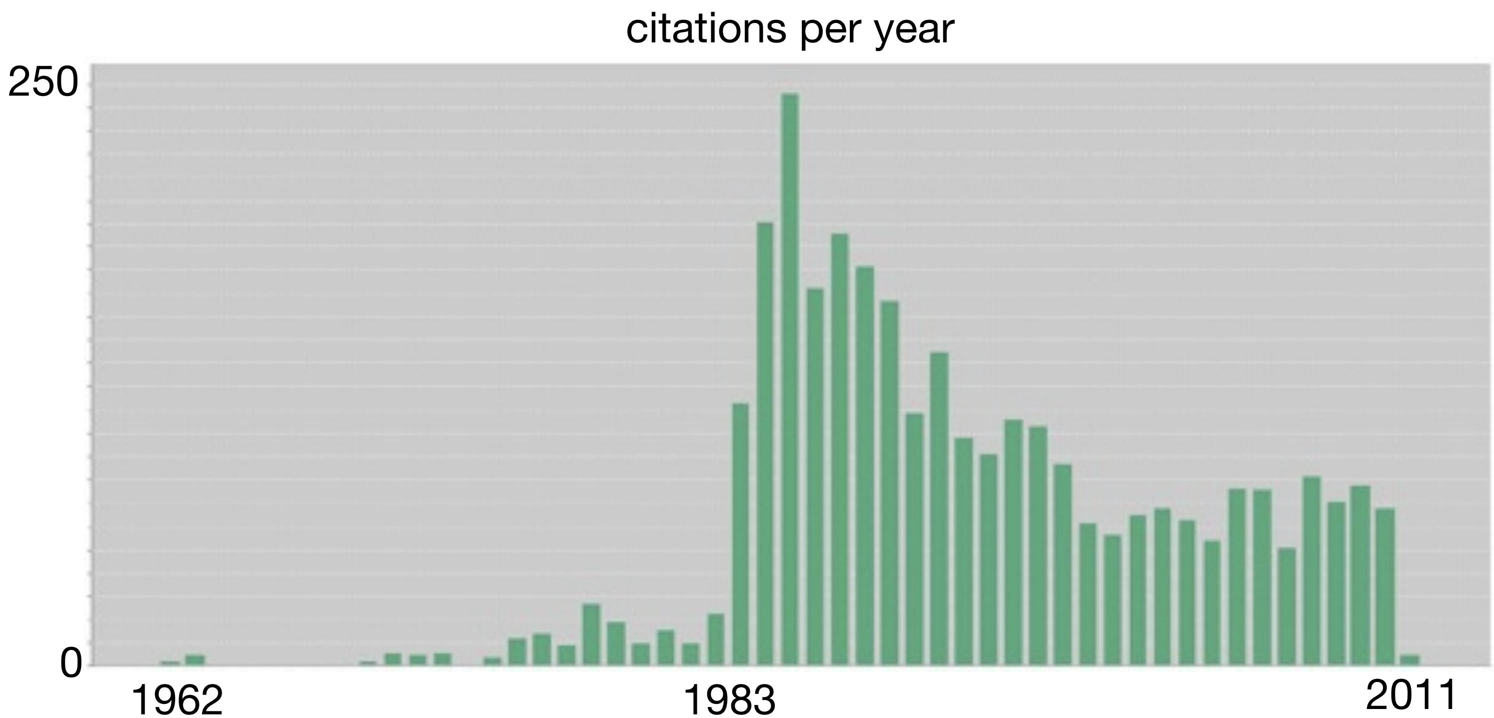




$$\gamma = \frac{1}{2\pi} \oint_{\Gamma} \nabla \varphi \cdot d\boldsymbol{l}$$

$$W = \frac{1}{4\pi} \int dx\, dy\; \vec{n} \cdot (\partial_x \vec{n} \times \partial_y \vec{n})$$

Discovery of the Skyrmion

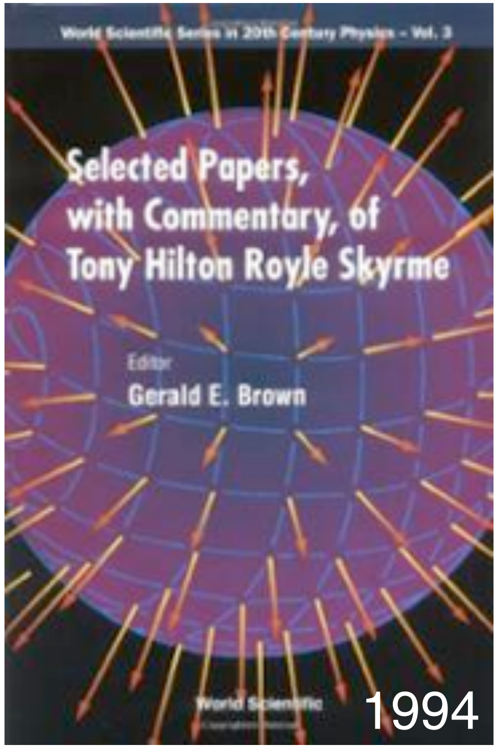


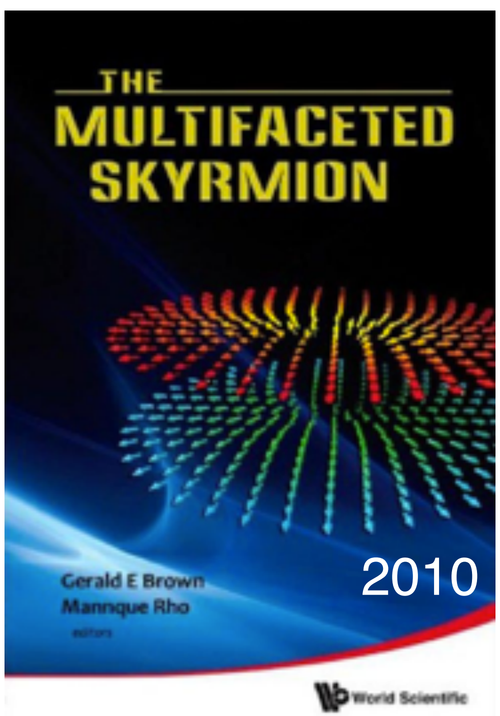
PRSL - Ser. A **260**, 130 (1961)
PRSL - Ser. A **262**, 237 (1961)
Nuclear Physics **31** 556 (1962)

ISI: >3006 citations
(170 before '83)

Ed Witten (ISI 68.800; h=124)

„Static properties of nucleons in the Skyrme model"
Adkins, Nappi, Witten, Nucl. Phys. B **228** 552 (1983)
ISI: 1484 citations

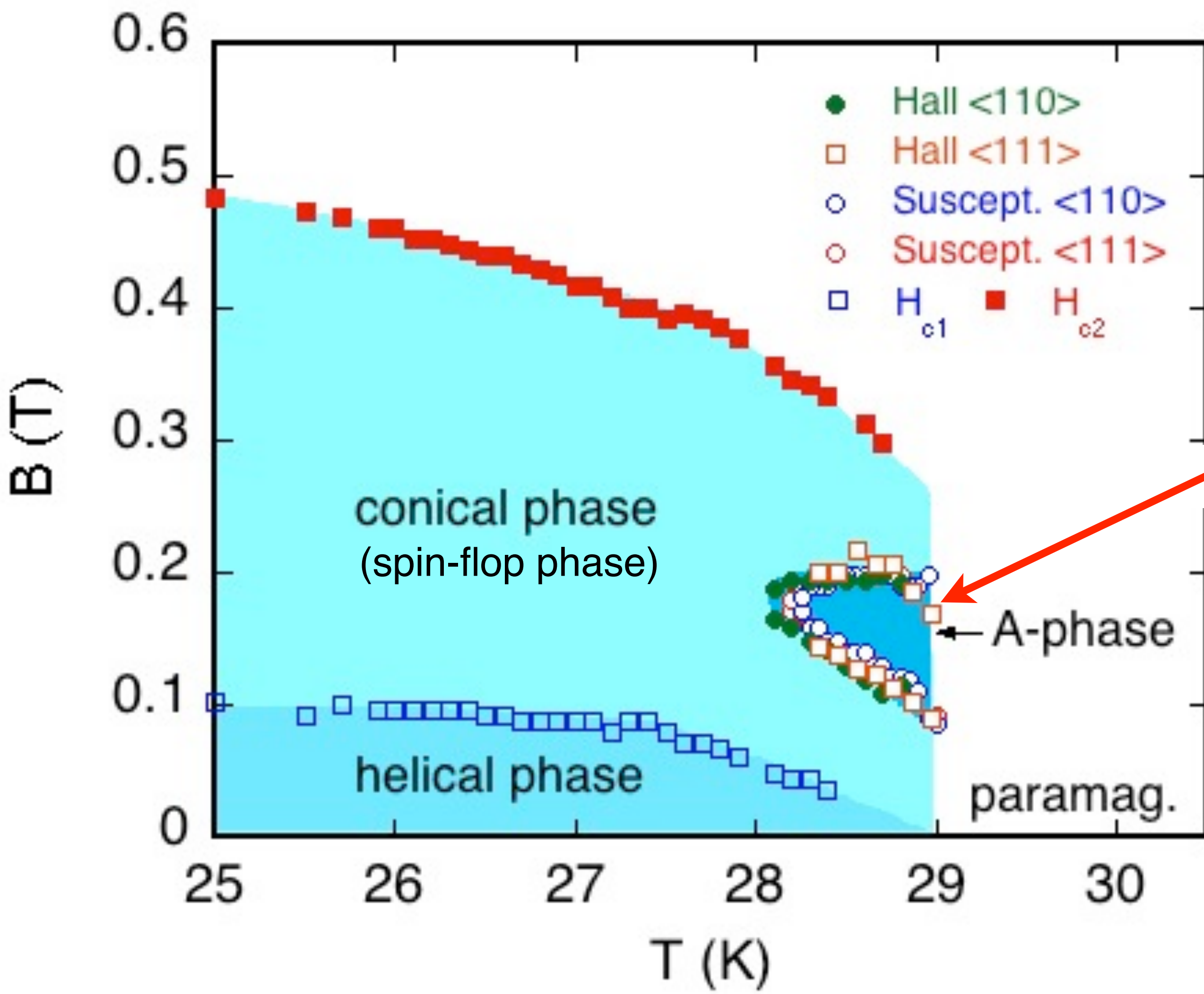


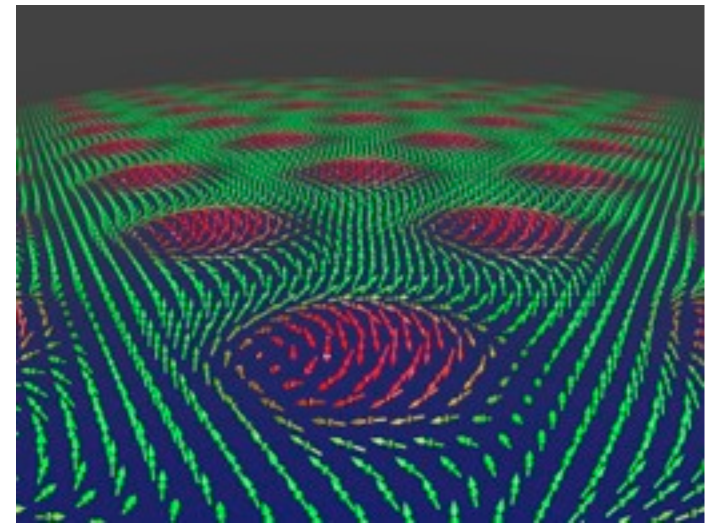


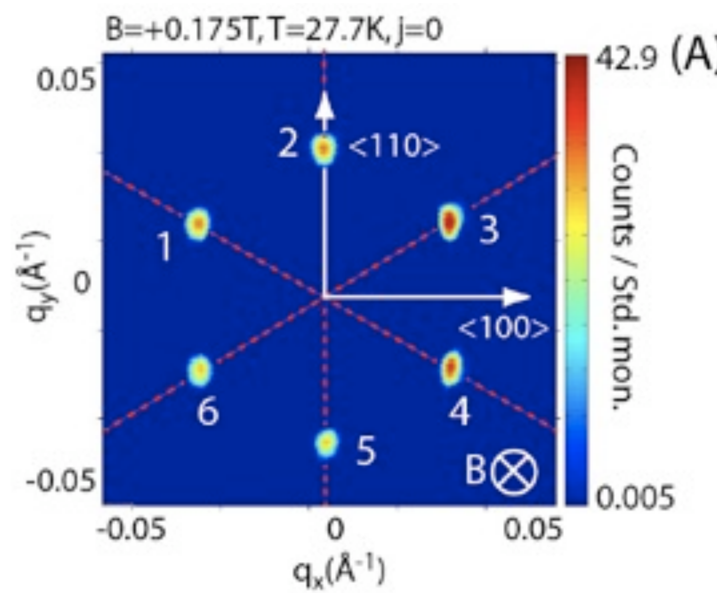
Contents:

- ***Hadrons and Nuclear Matter:***
  - Skyrmions and Nuclei *(R A Battye et al.)*
  - Electromagnetic Form Factors of the Nucleon in Chiral Soliton Models *(G Holzwarth)*
  - Exotic Baryon Resonances in the Skyrme Model *(D Diakonov & V Petrov)*
  - Heavy-Quark Skyrmions *(N N Scoccola)*
  - Skyrmion Approach to Finite Density and Temperature *(B-Y Park & V Vento)*
  - Half-Skyrmion Hadronic Matter at High Density *(H K Lee & M Rho)*
  - Superqualitions: Baryons in Dense QCD *(D K Hong)*
  - Rotational Symmetry Breaking in Baby Skyrme Models *(M Karliner & I Hen)*
- ***Condensed Matter:***
  - Spin and Isospin: Exotic Order in Quantum Hall Ferromagnets *(S M Girvin)*
  - Noncommutative Skyrmions in Quantum Hall Systems *(Z F Ezawa & G Tsitsishvili)*
  - Skyrmions and Merons in Bilayer Quantum Hall System *(K Moon)*
  - Spin and Pseudospin Textures in Quantum Hall Systems *(H A Fertig & L Brey)*
  - Half-Skyrmion Theory for High-Temperature Superconductivity *(T Morinari)*
  - Deconfined Quantum Critical Points *(T Senthil et al.)*
- ***String Theory:***
  - Skyrmion and String Theory *(S Sugimoto)*
  - Holographic Baryons *(P Yi)*
  - The Cheshire Cat Principle from Holography *(H B Nielsen & I Zahed)*
  - Baryon Physics in a Five-Dimensional Model of Hadrons *(A Pomarol & A Wulzer)*

Magnetic Phase Diagram of MnSi

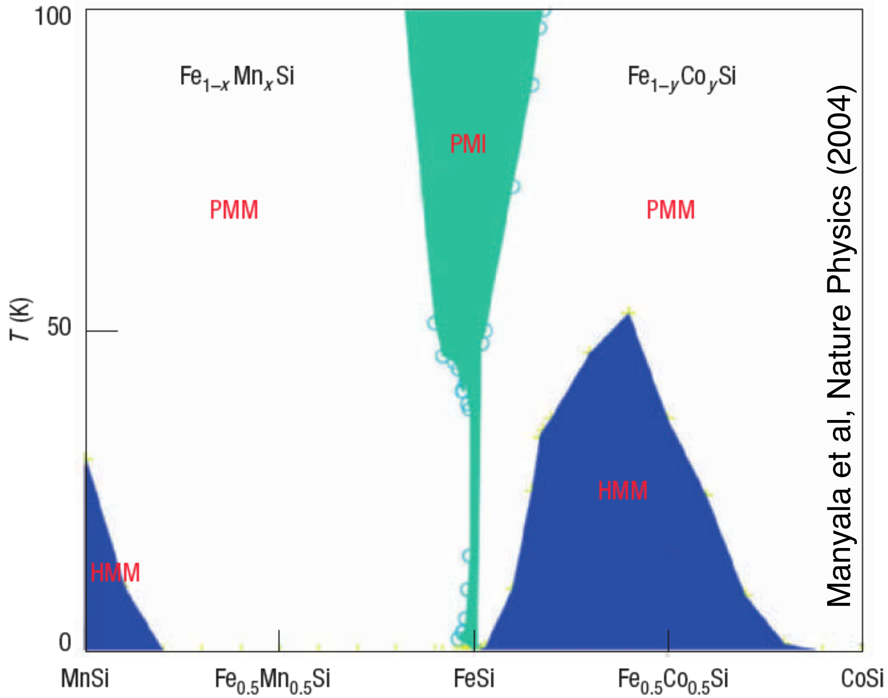


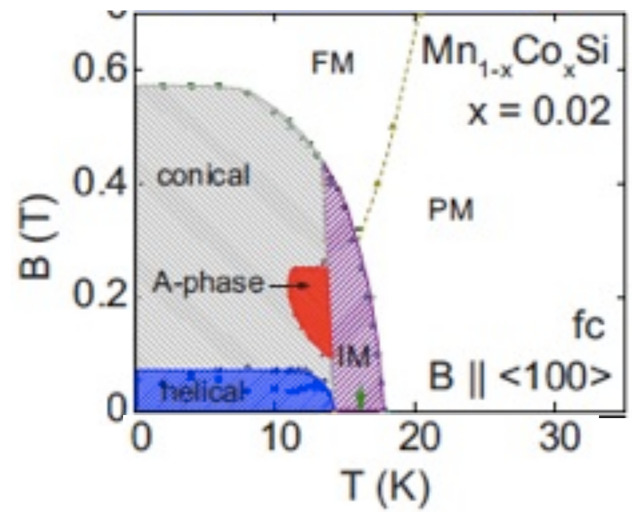


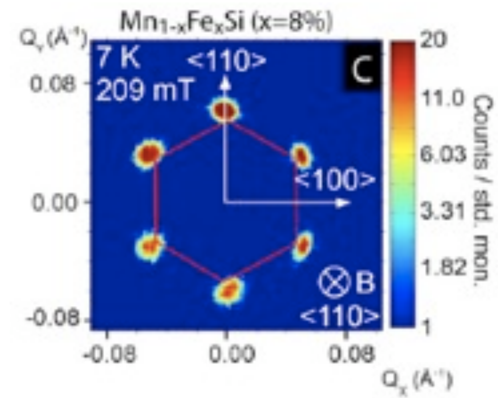


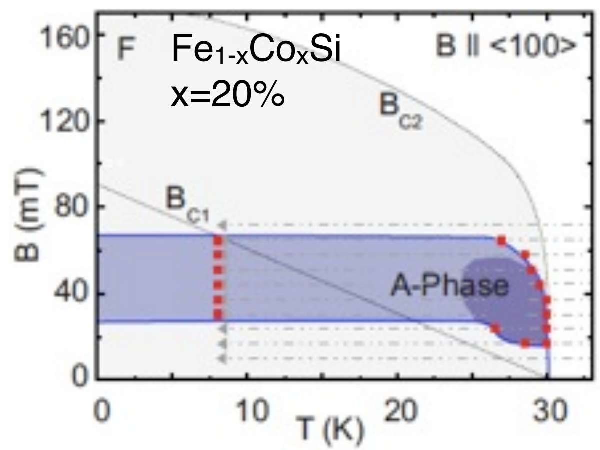
Mühlbauer, et al. Science **323**, 915 (2009)
Neubauer, et al. PRL **102** 186602 (2009)

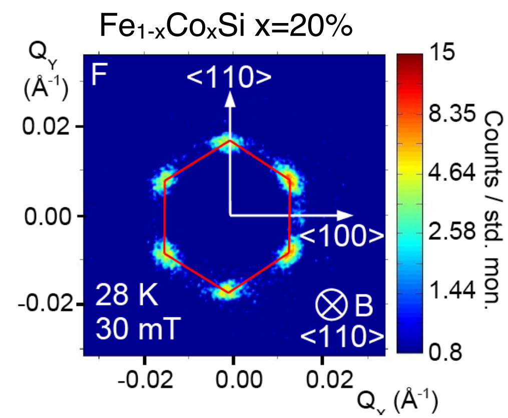
Magnetic Phase Diagram of B20 Compounds











Mühlbauer, et al. Science **323**, 915 (2009)
Neubauer, et al. PRL **102** 186602 (2009)

Münzer, et al. PRB(R) **81** 041203 (2010)
Adams, et al. J. Phys. Conf. Series (2010)
Bauer, et al. PRB(R) **82** 064404 (2010)

$P2_13$ insulators

Cu_2OSeO_3

Seki al., Science **336** 198 (2012)

Adams et al., PRL, **108** 237204 (2012)

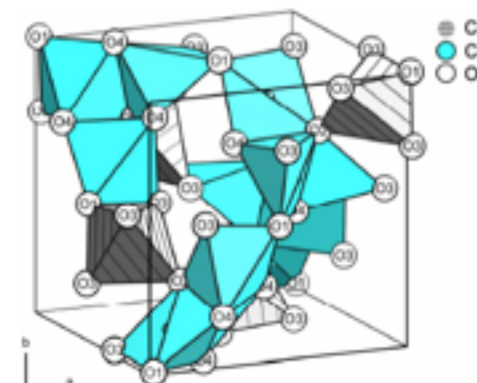
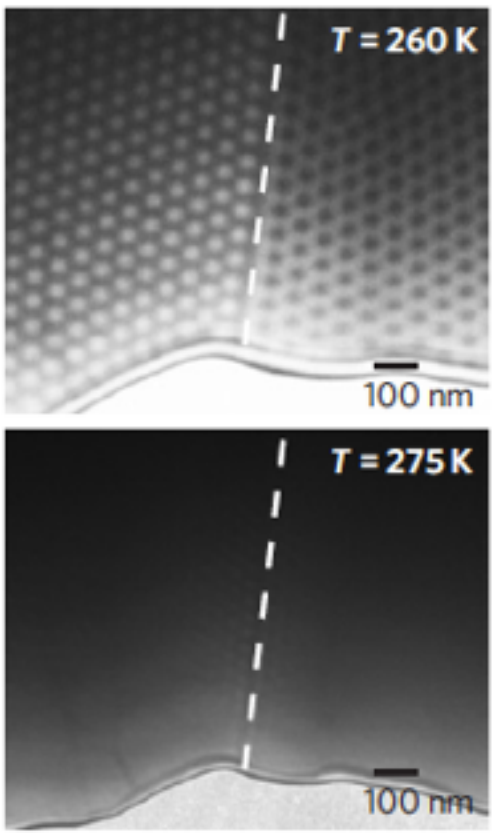


illustration from Bos et al. (2008)

Real Space Observation with Lorentz Force Microscopy

at room temperature

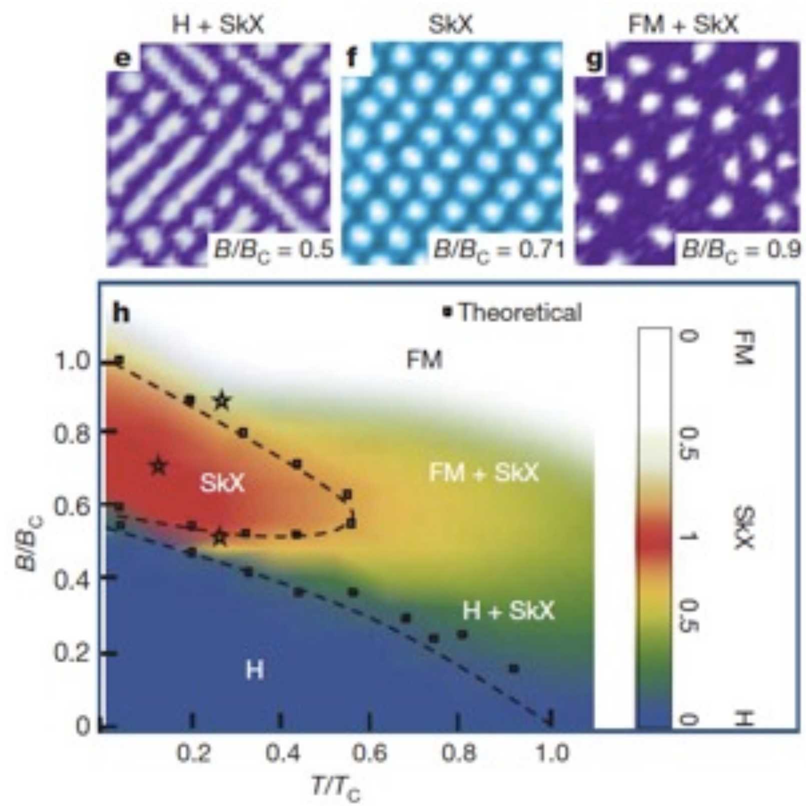
FeGe



Yu et al., Nat. Mater. **10** 106 (2010)

semiconductor

$Fe_{0.5}Co_{0.5}Si$

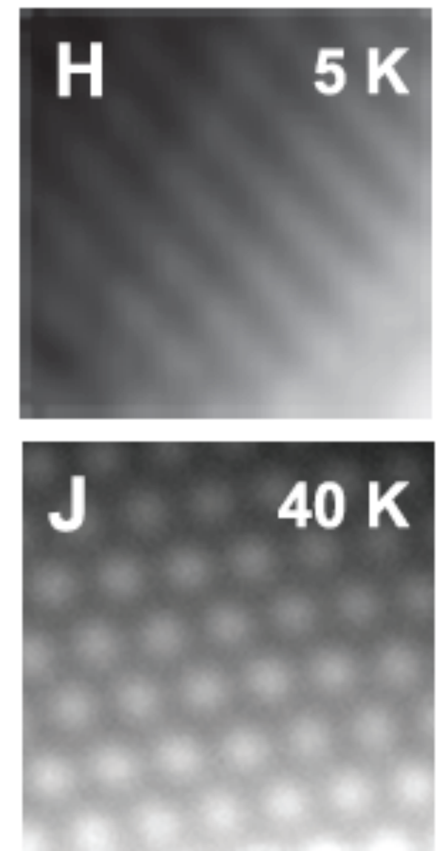


Münzer, et al. PRB(R) **81** 041203 (2010)
Yu et al., Nature **465** 901 (2010)

CP & Rosch, Nature (N&V) **465** 880 (2010)

insulator

Cu_2OSeO_3



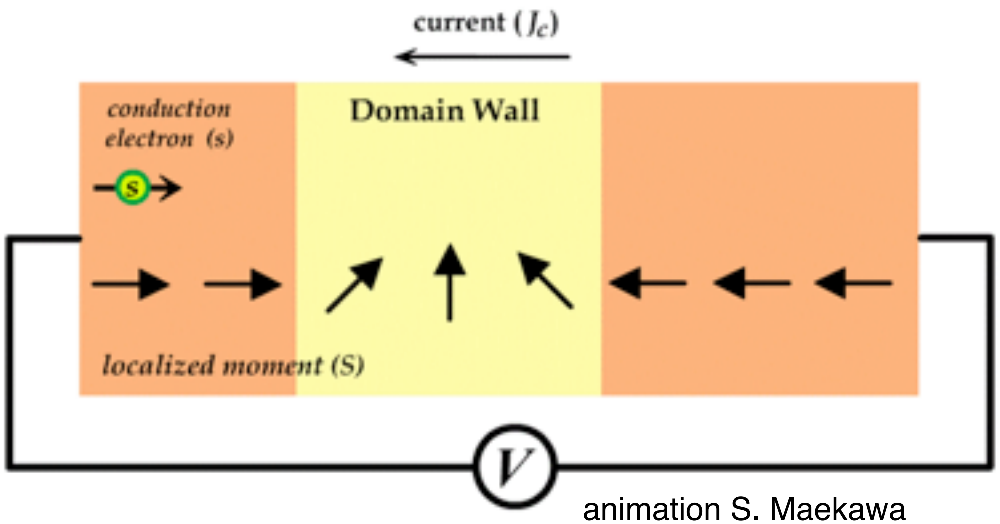
Seki al., Science **336** 198 (2012)
Adams et al., PRL, **108** 237204 (2012)

Outline

- Introductory Remarks on Skyrmions
- Emergence of Skyrmions in Chiral Magnets
  - ➢ Fluctuation-Induced First Order Transition
  - ➢ Magnetic Phase Diagram
  - ➢ Nature of the A-Phase
  - ➢ Poor Man‘s Probe of Topology
- Topological Unwinding of Skyrmions
- Formation of a Topological Non-Fermi Liquid (?)
  - ➢ Non-Fermi Liquid Puzze in MnSi
  - ➢ Hall Effect under Pressure
- List of Untold Stories

Challenges in Spintronics

Not in this talk



animation S. Maekawa

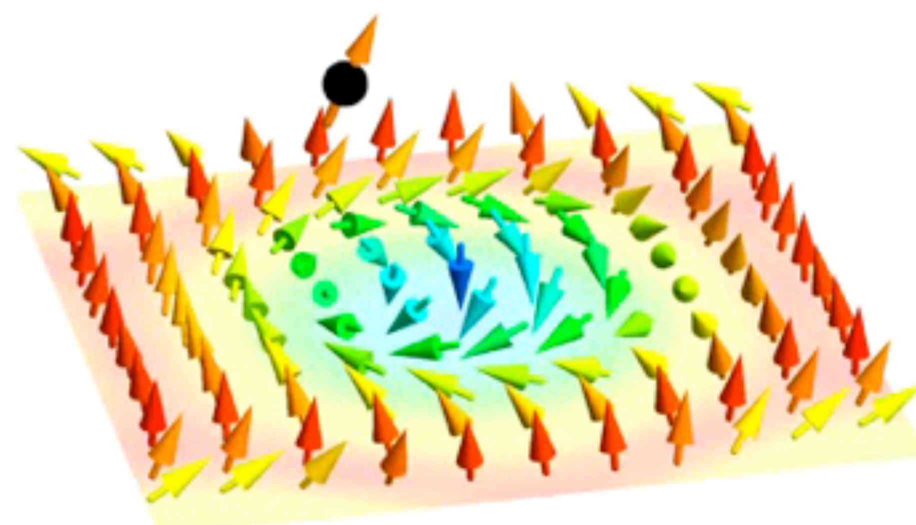
typical current density
10^{12} A/m^2

Emergent Electrodynamics of Skyrmions

$$B_i^e = \frac{\hbar}{2}\epsilon_{ijk}\hat{n}\cdot(\partial_j\hat{n}\times\partial_k\hat{n})$$

$$E_i^e = \hbar\,\hat{n}\cdot(\partial_i\hat{n}\times\partial_t\hat{n})$$

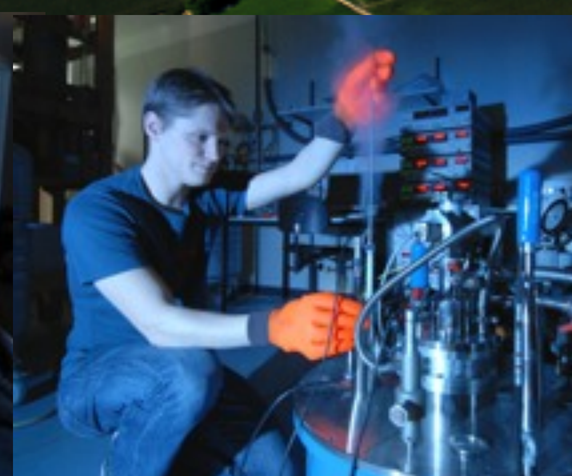
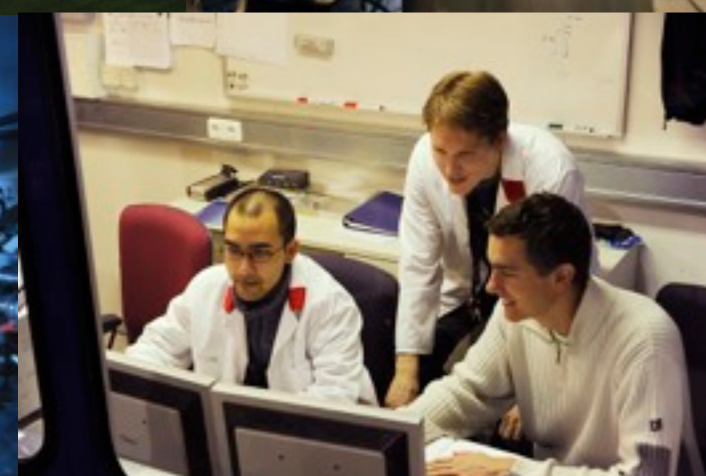
current density: 10^6 A/m^2 !!!



animation A. Rosch

Jonietz et al, Science **330**, 1648 (2010)
Schulz et al. Nature Physics **8** 301 (2012)
Everschor et al., PRB **86** 054432 (2012)



Collaborations

samples

A. Bauer

A. Neubauer
W. Münzer
S. Gottlieb

bulk properties

R. Ritz
C. Schnarr
M. Halder
C. Franz
M. Wagner
F. Rucker

M. Hirschberger[1]
P. Niklowitz[3]
T. Schulz[4]
M. Rahn[5]
F. Birkelbach

neutron scattering

T. Adams
A. Chacon
J. Kindervater
G. Brandl

S. Dunsiger
M. Janoschek[2]
F. Jonietz
F. Bernlochner
A. Tischendorf

S. Mühlbauer
R. Georgii
W. Häußler
P. Link
B. Pedersen
T. Keller (MPI)
P. Böni

[1]Princeton [3]London
[2]Los Alamos [4]Mainz [5]Oxford

erc TOPFIT

Collaborations

Köln
R. Bamler
S. Buhrandt
J. Waizner
C. Schütte
K. Everschor
M. Garst
B. Binz
A. Rosch

Utrecht
R. Duine

Berkeley
J. Koralek
D. Maier
J. Orenstein
A. Vishwanath

München
T. Schwarze
D. Grundler
R. Hackl (WMI)

Dresden
P. Milde
D. Köhler
J. Seidel
L. Eng

Lausanne
H. Berger

Braunschweig
P. Lemmens

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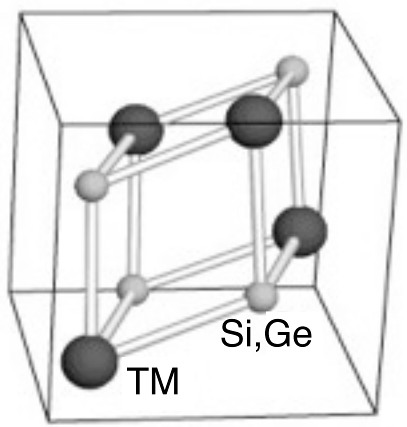
Hierarchical Energy Scales in B20 Compounds

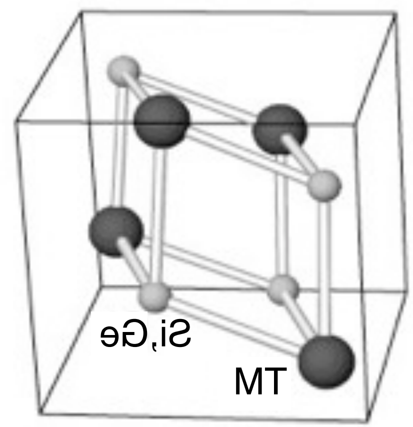
and the Fluctuation-Induced First Order Transition

Hierarchical Energy Scales in B20 compounds

Landau-Lifshitz vol. 8, §52



B20: no inversion center



B20: no inversion center

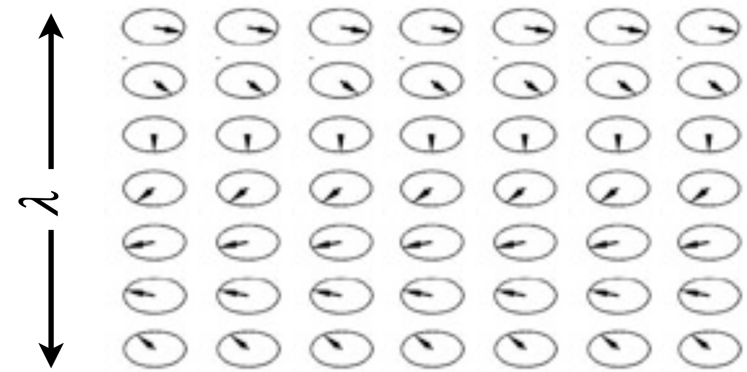
left-handed

right-handed

(1) ferromagnetism

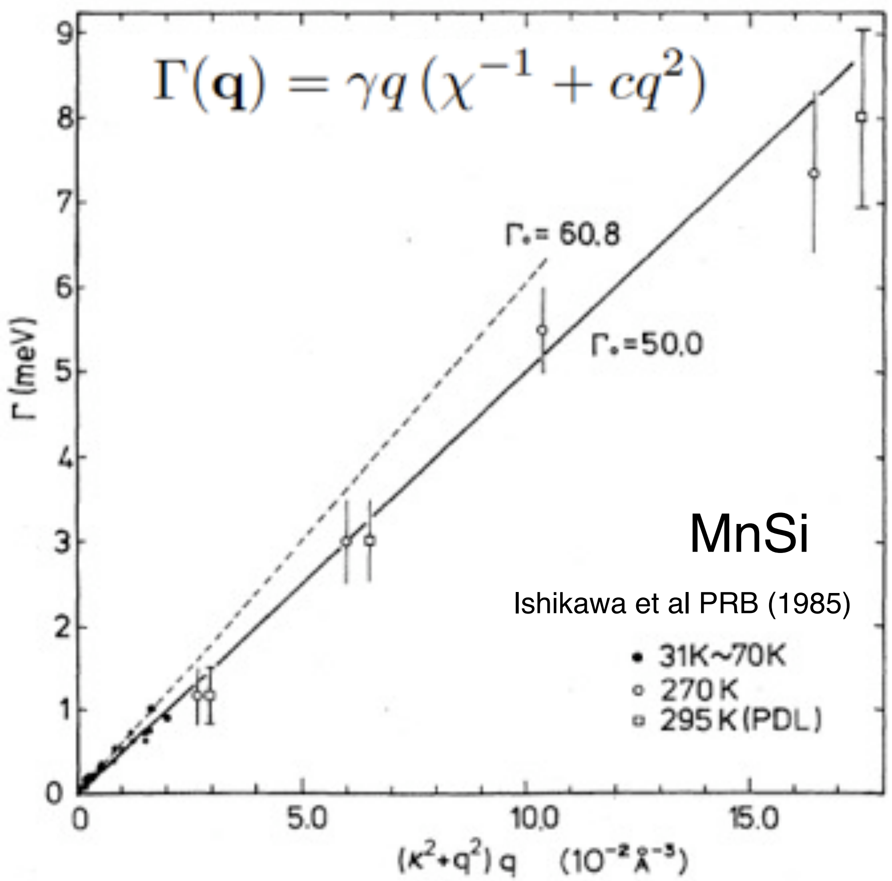
(2) Dzyaloshinsky-Moriya

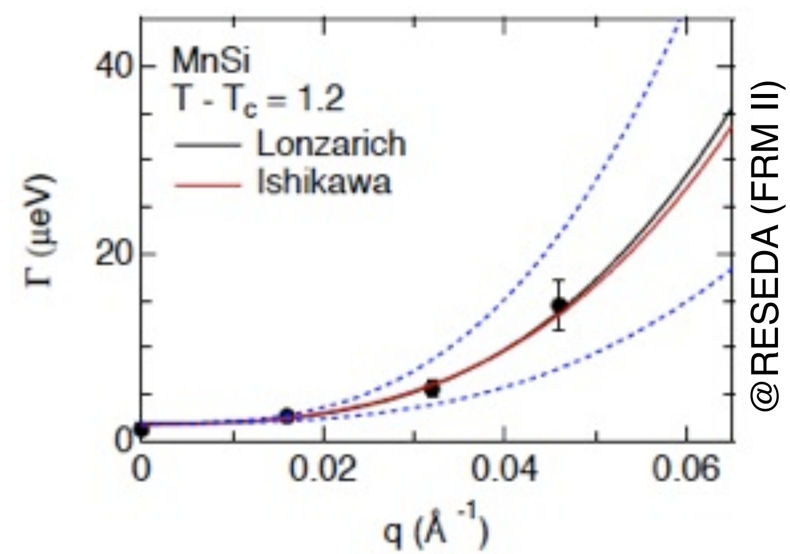
(3) crystal field ($P2_13$):
locked to <111> or <100>



	T_N (K)	λ (Å)
MnGe	170	30 to 60
$Mn_{1-x}Fe_xSi$	< 28	180 to 120
$Fe_{1-x}Co_xSi$	< 45	> 300
FeGe	280	700
Cu_2OSeO_3	54	620

Breakthrough for „Itinerant Spin Fluctuations“



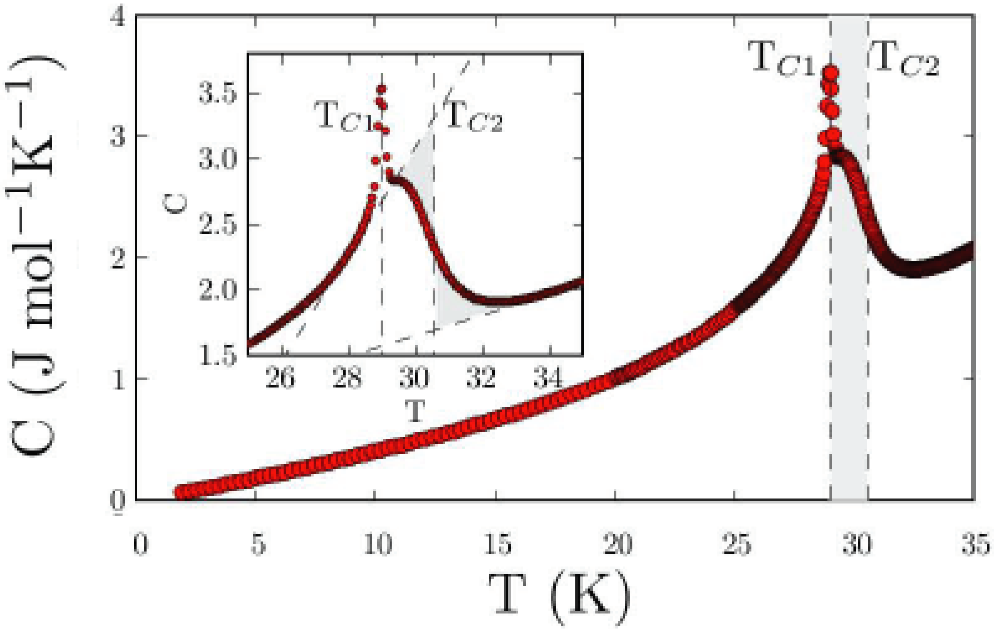


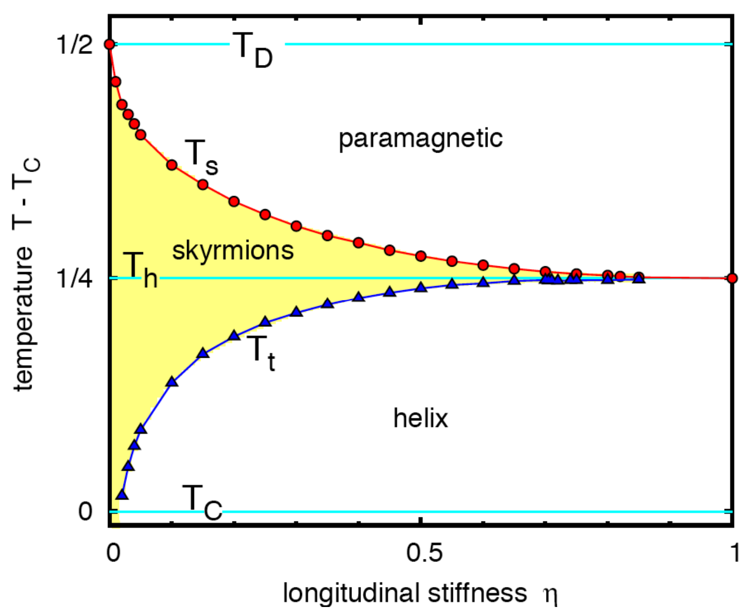
$$T_c = 2.387 c M_0^{3/2} \frac{(\hbar\gamma)^{1/4}}{k_B}$$

Property	Experiment	Present model
$\chi^{-1}(T)$ $2T_c \lesssim T \lesssim 10\,T_c$	Linear[c]	Linear[c,d]
T_c(K)	29.5(5)	31
p_{eff}/p_0[e]	5.5(4)	4.7

Lonzarich JMMM **45** 43 (1984)
Lonzarich, Taileffer. J. Phys. Cond. Matter **18** 4339 (1985)

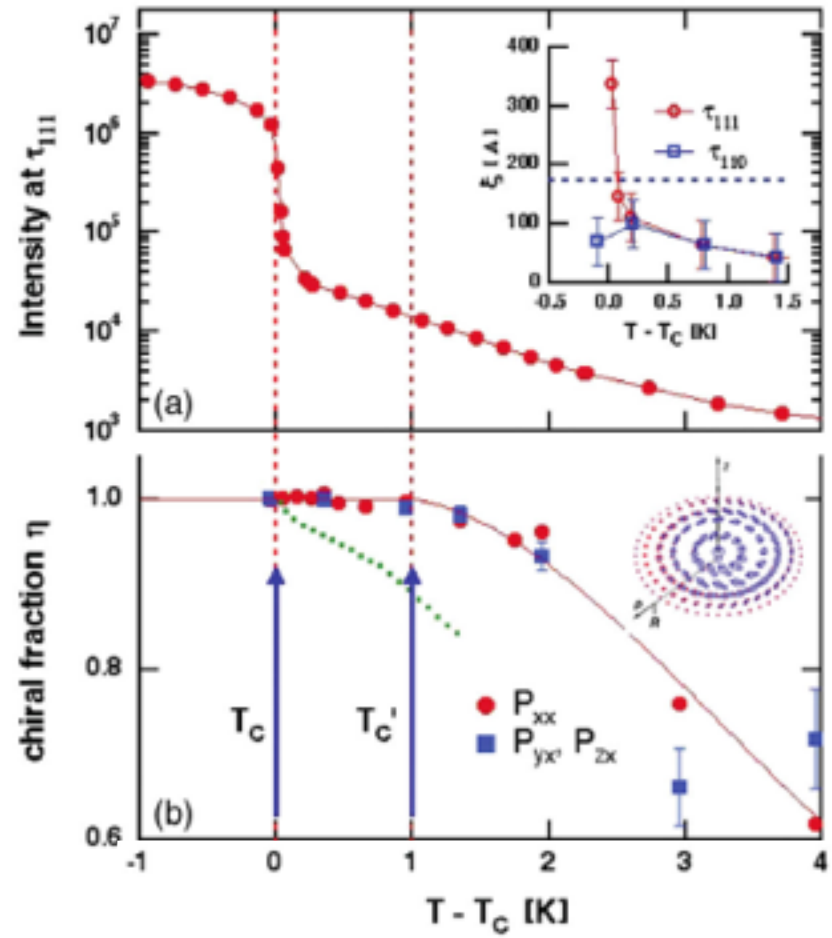
Prediction of a Spontaneous Skyrmion Phase





Rößler, Bogdanov, CP, Nature **442**, 797 (2006)

claim of a skyrmion liquid

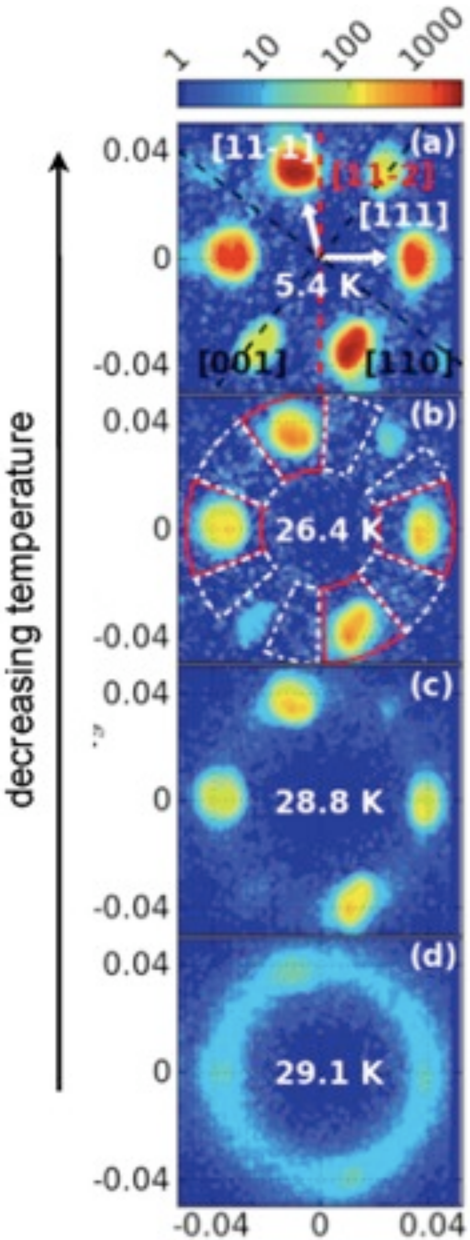


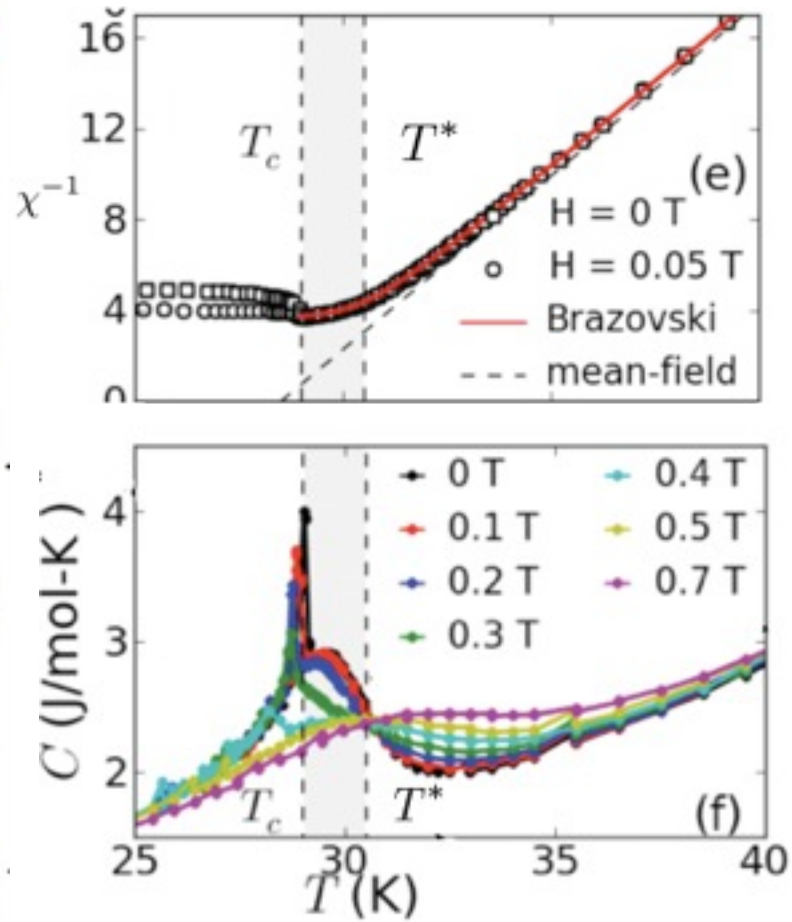
Pappas et al., PRL **102**, 197202 (2009)

cf Hamann et al., PRL **107**, 037207 (2011)

Fluctuation-Induced First Order Transition

a helimagnetic Brazovskii transition





experiments @ MIRA, FRM II

M. Janoschek, M. Garst et al.
arXiv/1205.4780

FM exchange
$J\, a = 11\text{meV}$

DM-interaction
$D\, a^2 = J\, Q\, a^2 = 1.7\text{meV}$

cubic anisotropy
$J_1\, a = 0.37\text{meV}$

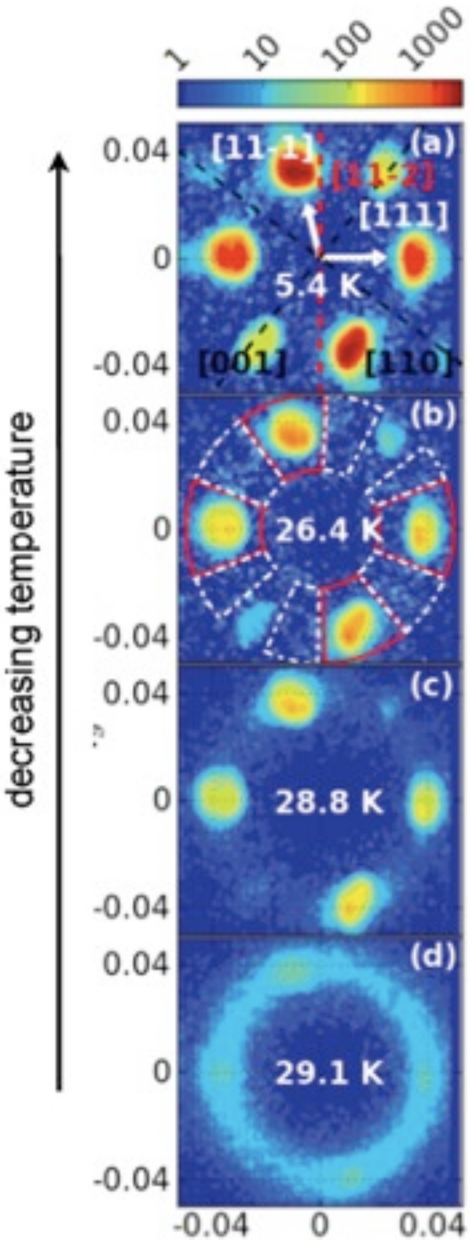
(*a*: lattice constant)

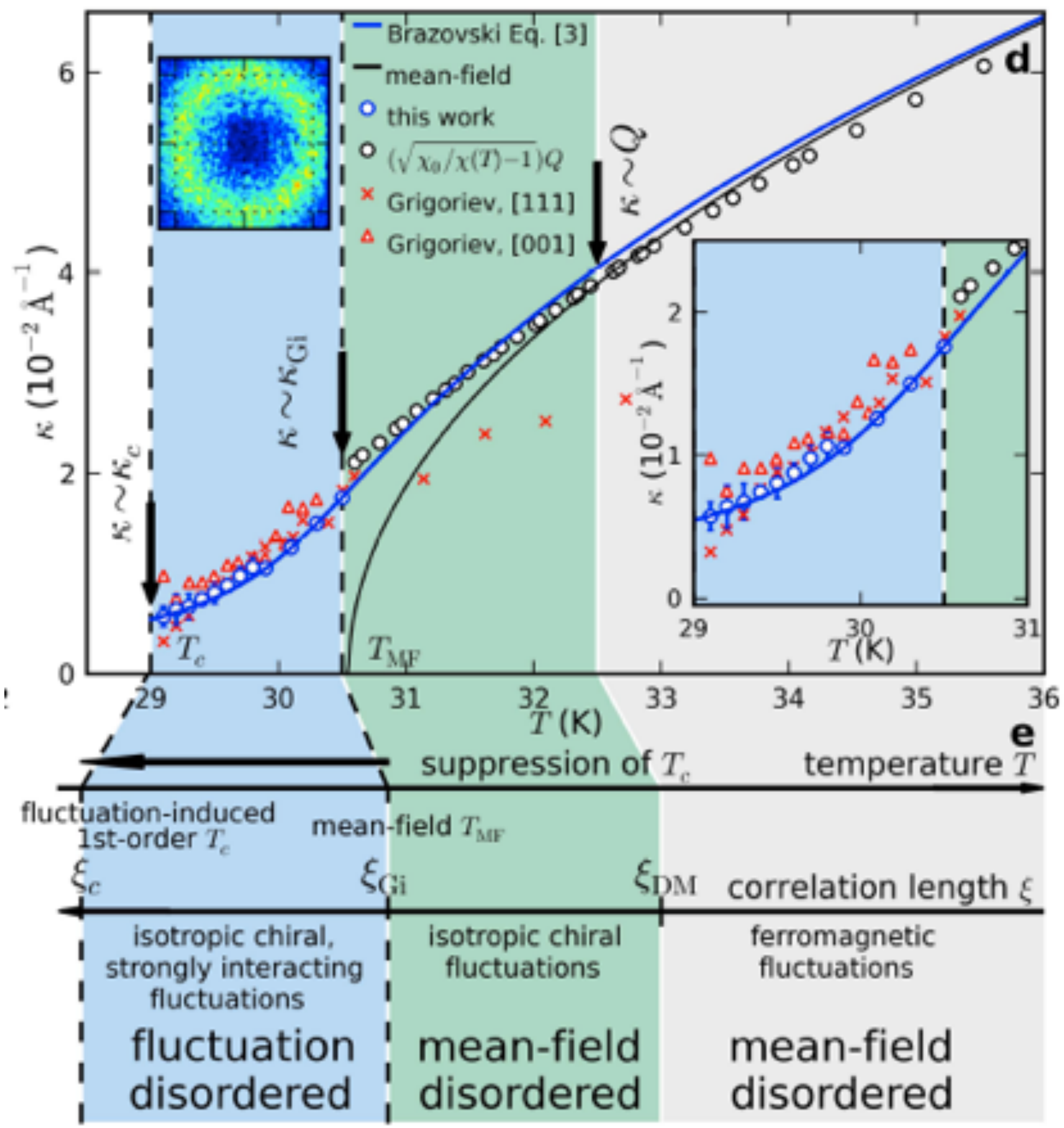
cf. claim of a Bak-Jensen
1[st] order transition

S. Grigoriev et al., PRB **81**, 144413 (2010)

Fluctuation-Induced First Order Transition

a helimagnetic Brazovskii transition

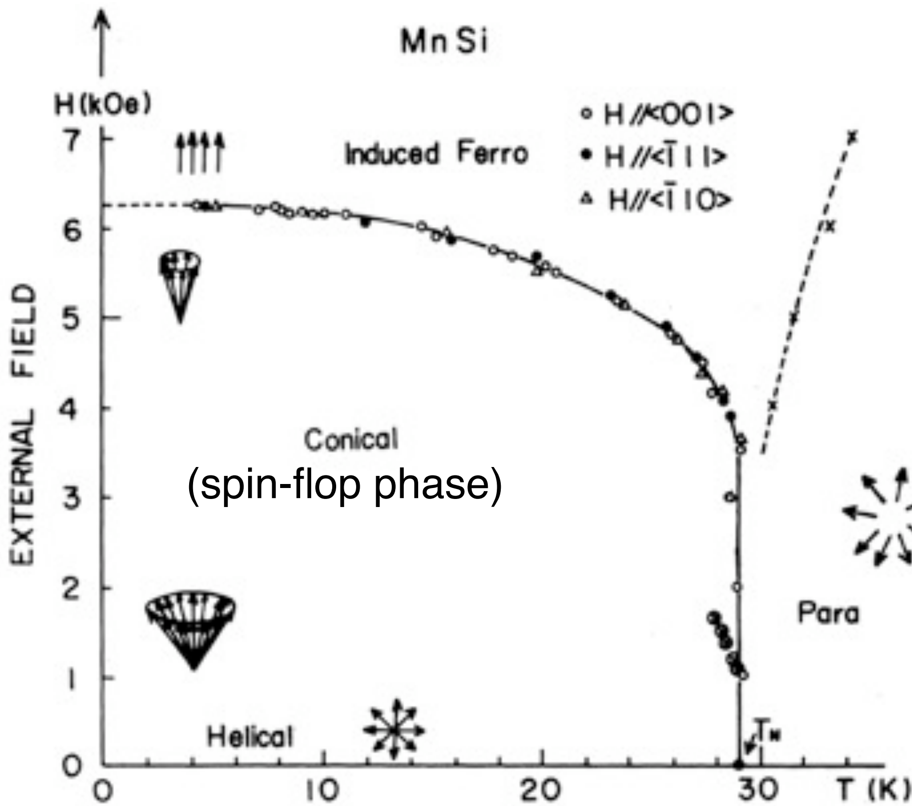




M. Janoschek, M. Garst et al. arXiv/1205.4780

Magnetic Phase Diagram of B20 Compounds

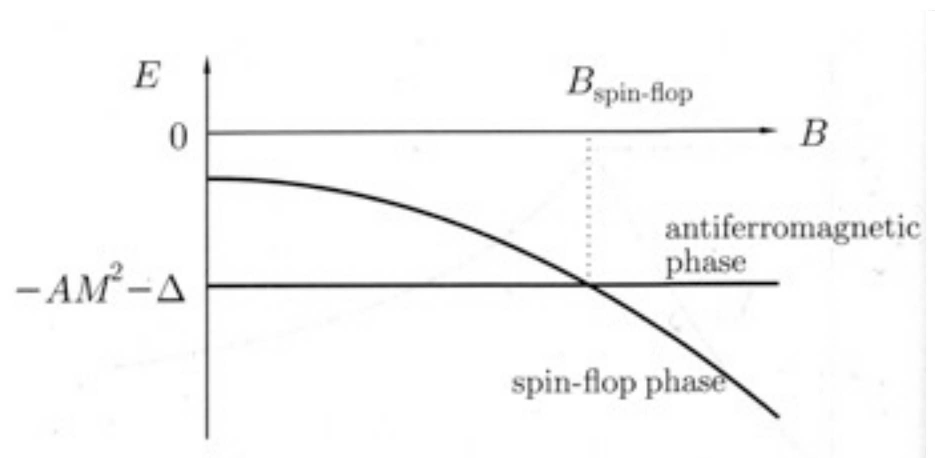
Magnetic Phase Diagram of B20 Compounds

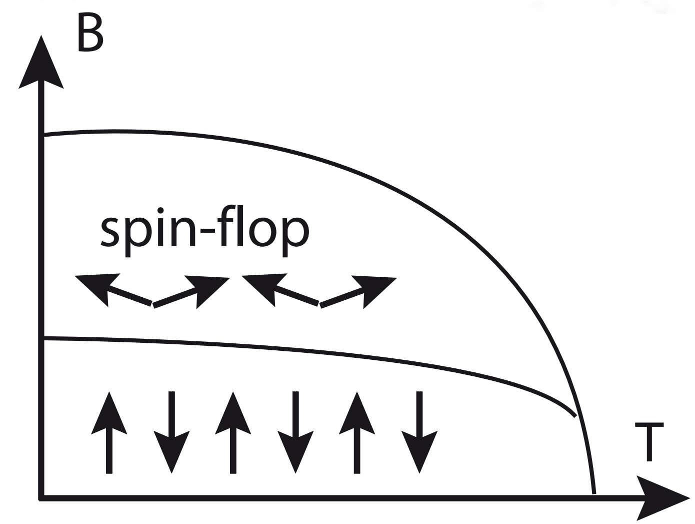


Ishikawa & Arai JPSJ **53**, 2726 (1984)

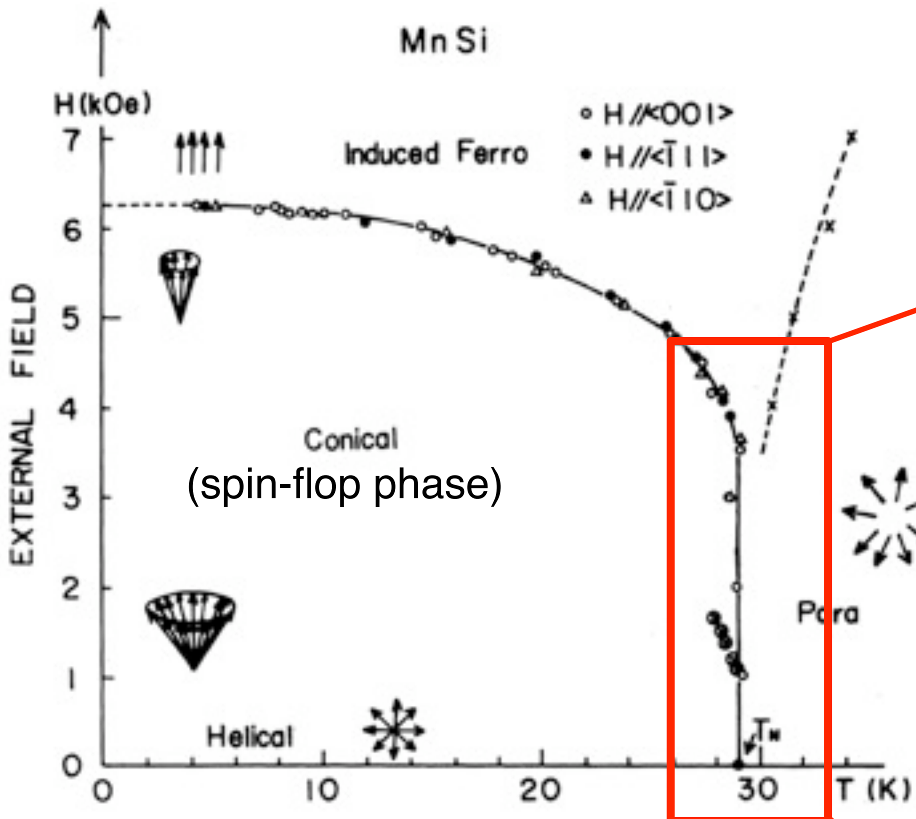
mostly a spin-flop phase

$$F[\vec{M}] = \Delta F^{(\mathrm{FM})} + \Delta F^{(\mathrm{DM})} + \Delta F^{(\mathrm{aniso})}$$

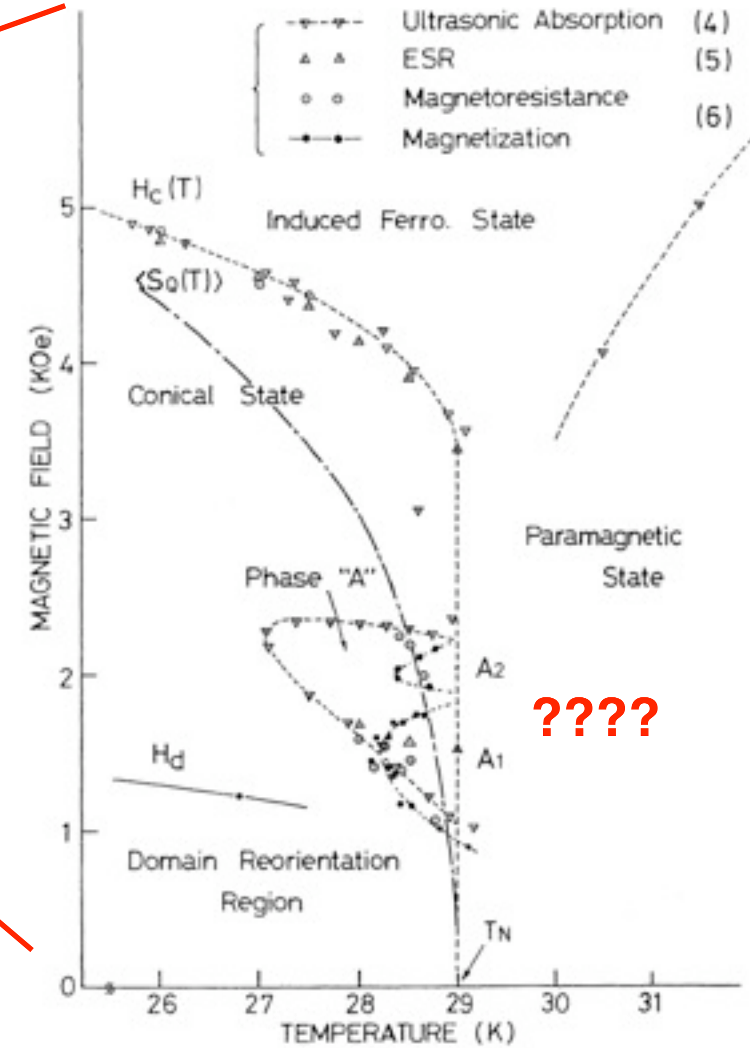




Magnetic Phase Diagram of B20 Compounds

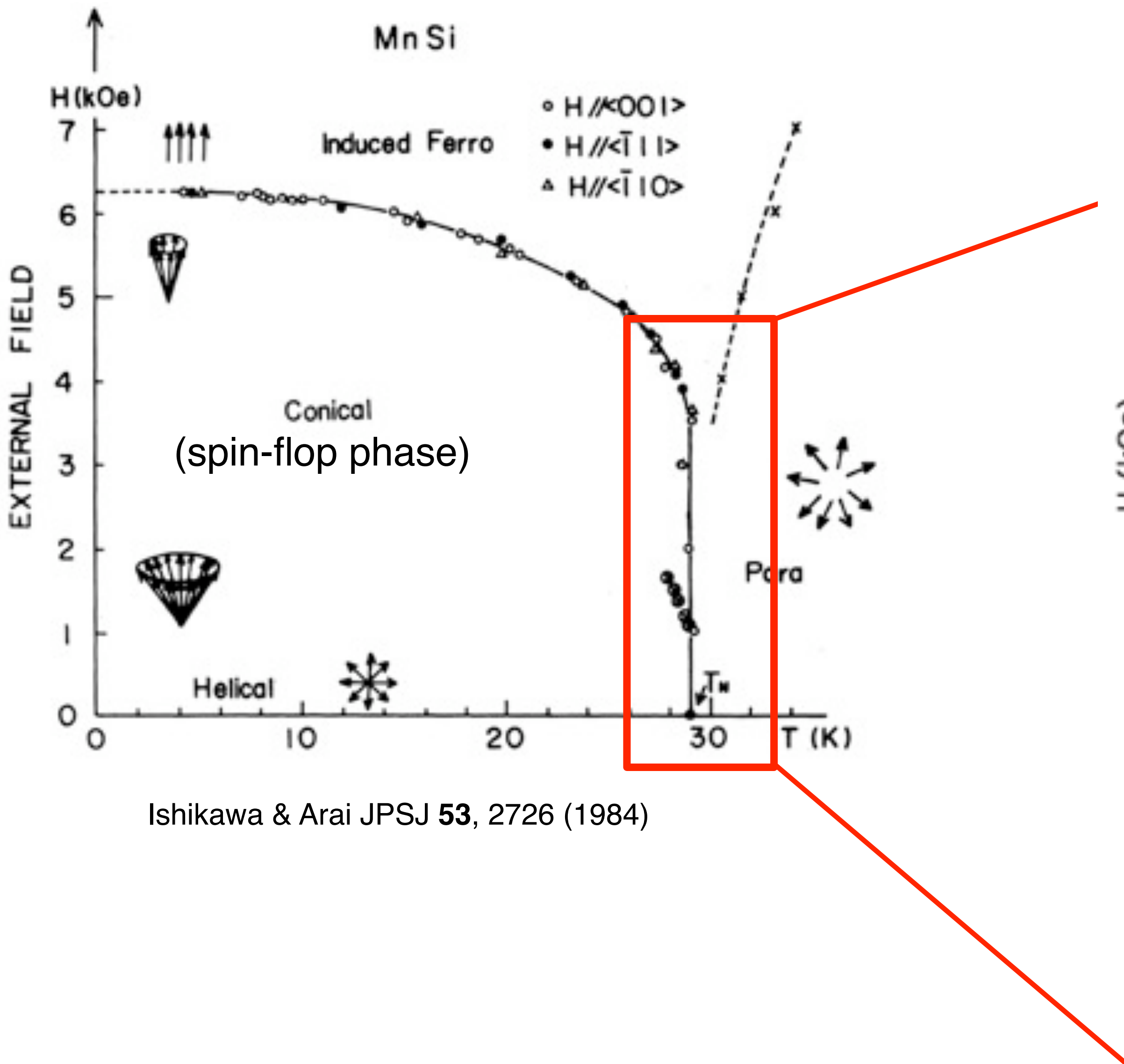


Ishikawa & Arai JPSJ **53**, 2726 (1984)

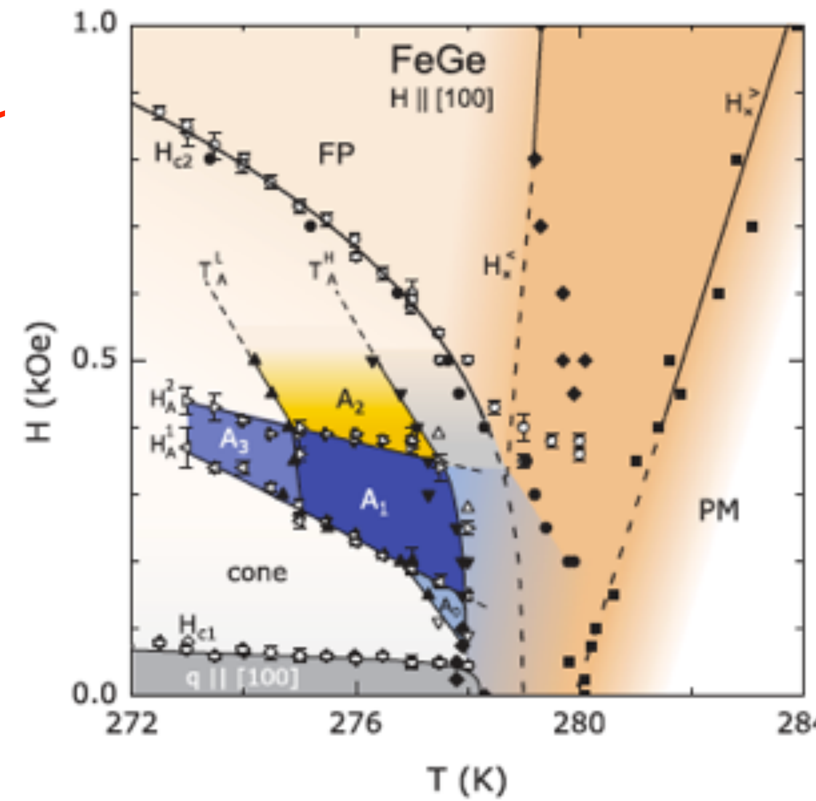


Kadowaki JPSJ **51**, 2433 (1982)

Magnetic Phase Diagram of B20 Compounds



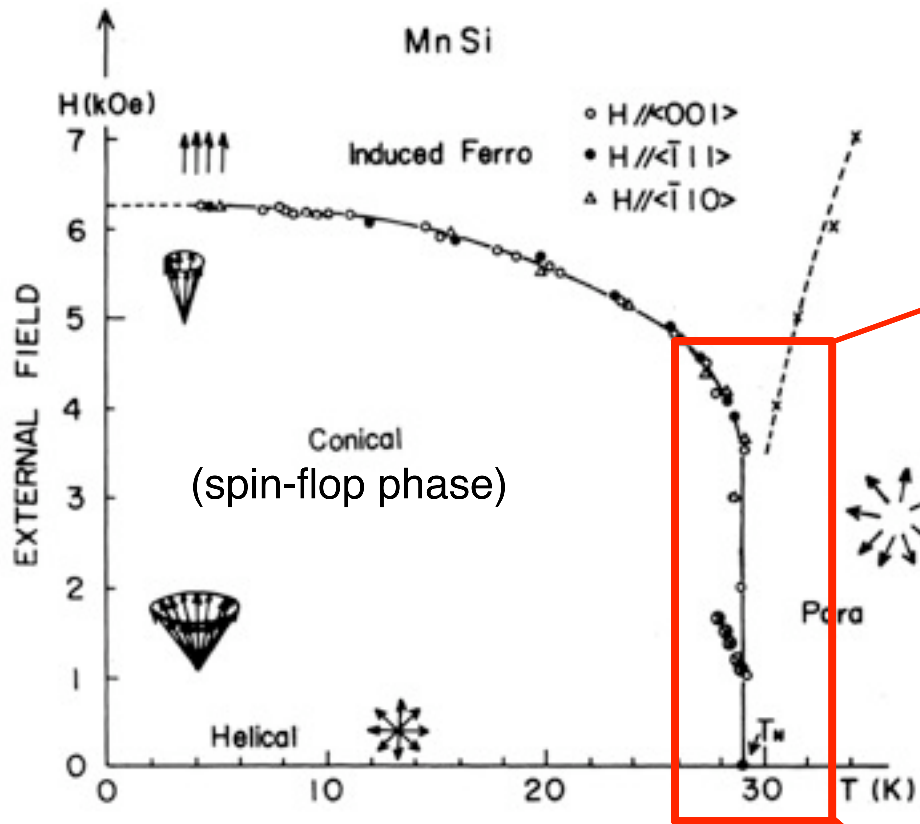
Ishikawa & Arai JPSJ **53**, 2726 (1984)



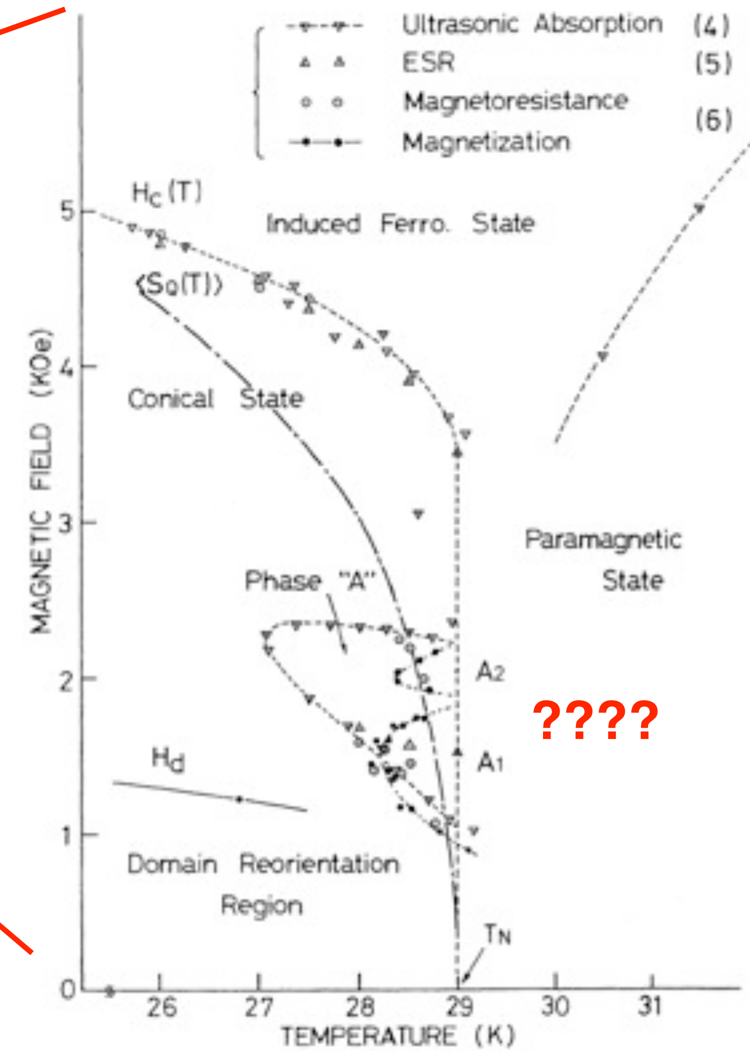
Wilhelm et al., PRL **107**, 127203 (2011)

purly based on
ac susceptibility @ 1 kHz
ill-defined sample shape

Magnetic Phase Diagram of B20 Compounds

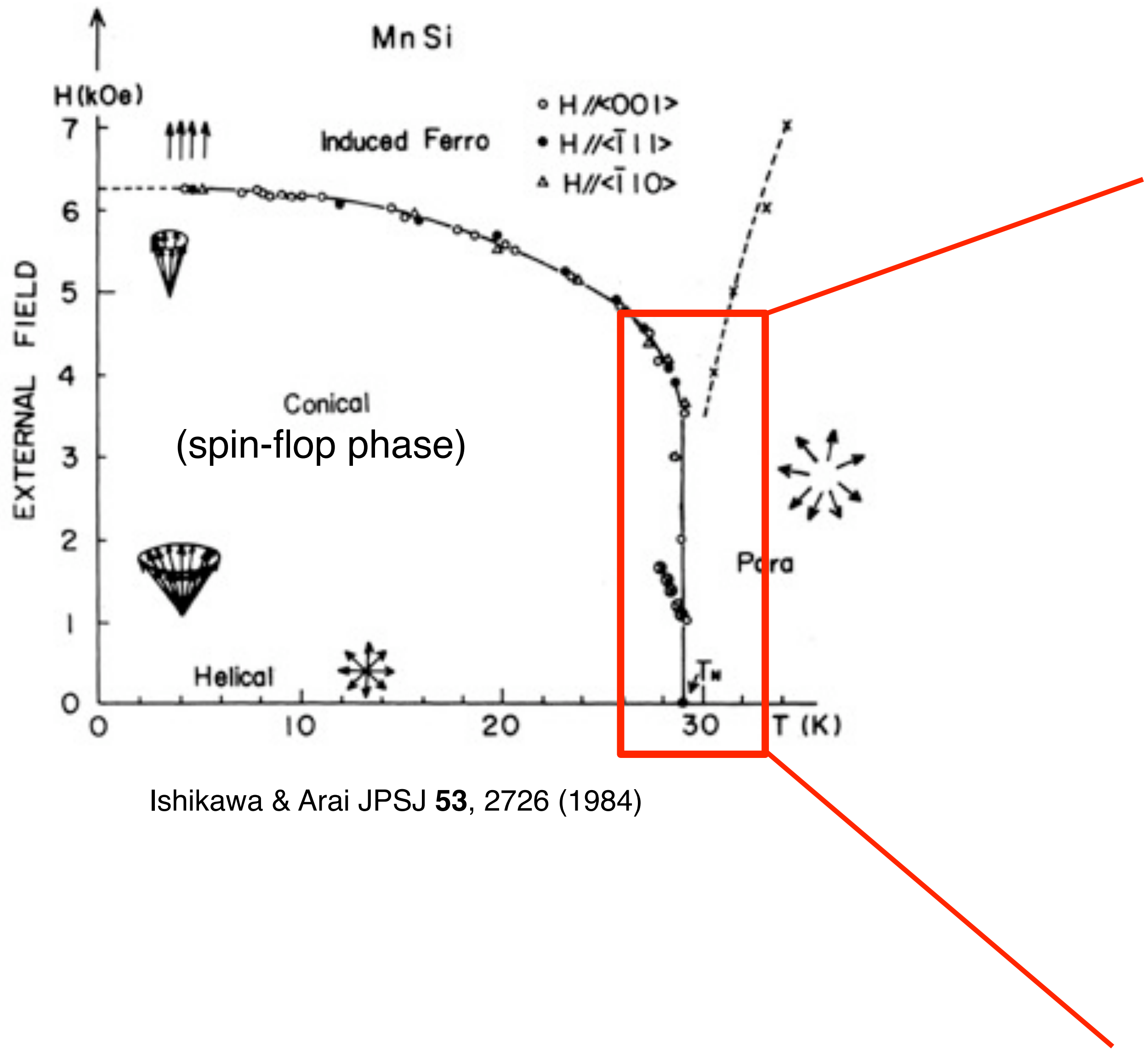


Ishikawa & Arai JPSJ **53**, 2726 (1984)

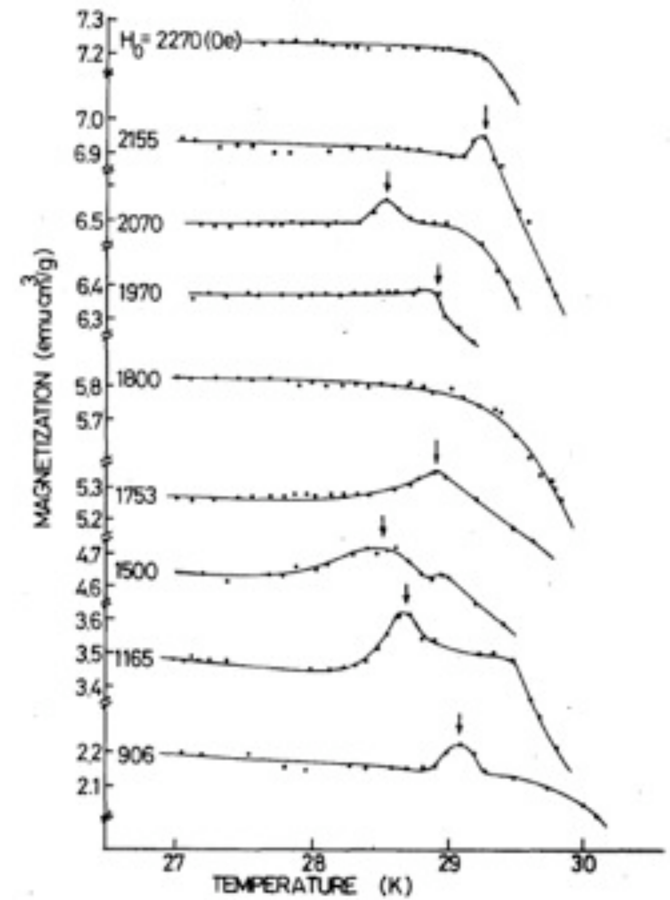


Kadowaki JPSJ **51**, 2433 (1982)

Magnetic Phase Diagram of B20 Compounds

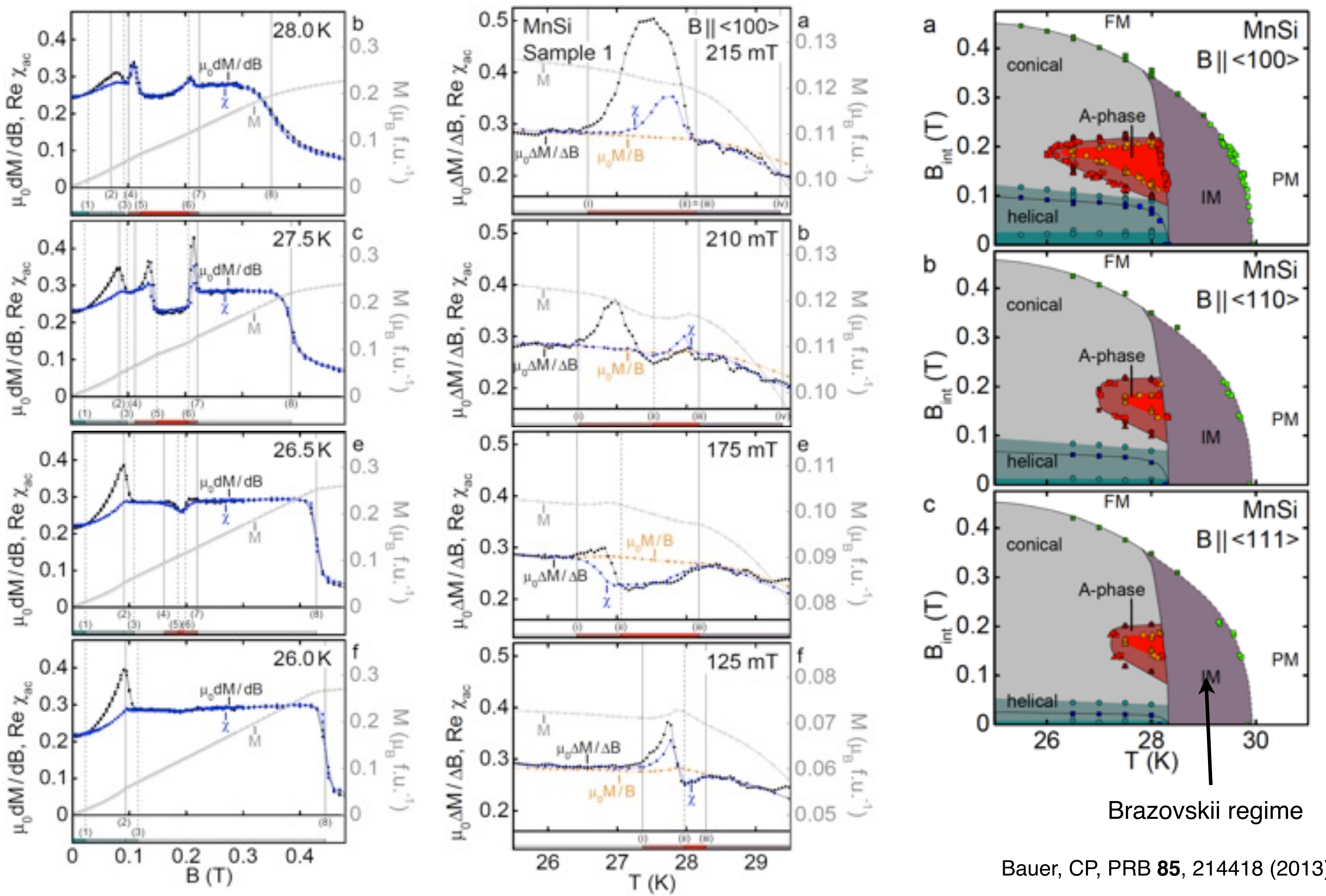


Ishikawa & Arai JPSJ **53**, 2726 (1984)



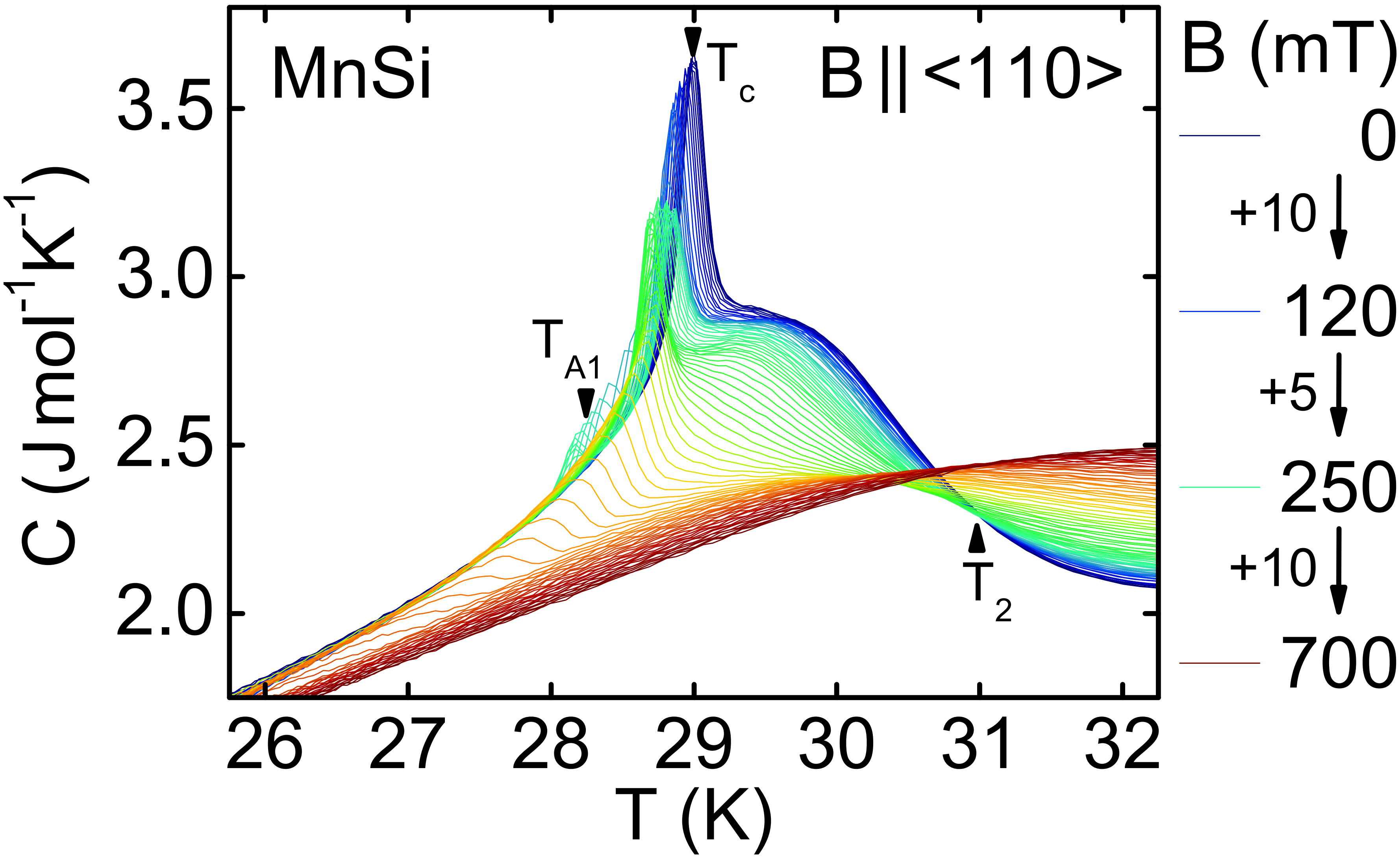
Kadowaki JPSJ **51**, 2433 (1982)

Magnetic Phase Diagram of MnSi Revisited



Bauer, CP, PRB **85**, 214418 (2013)

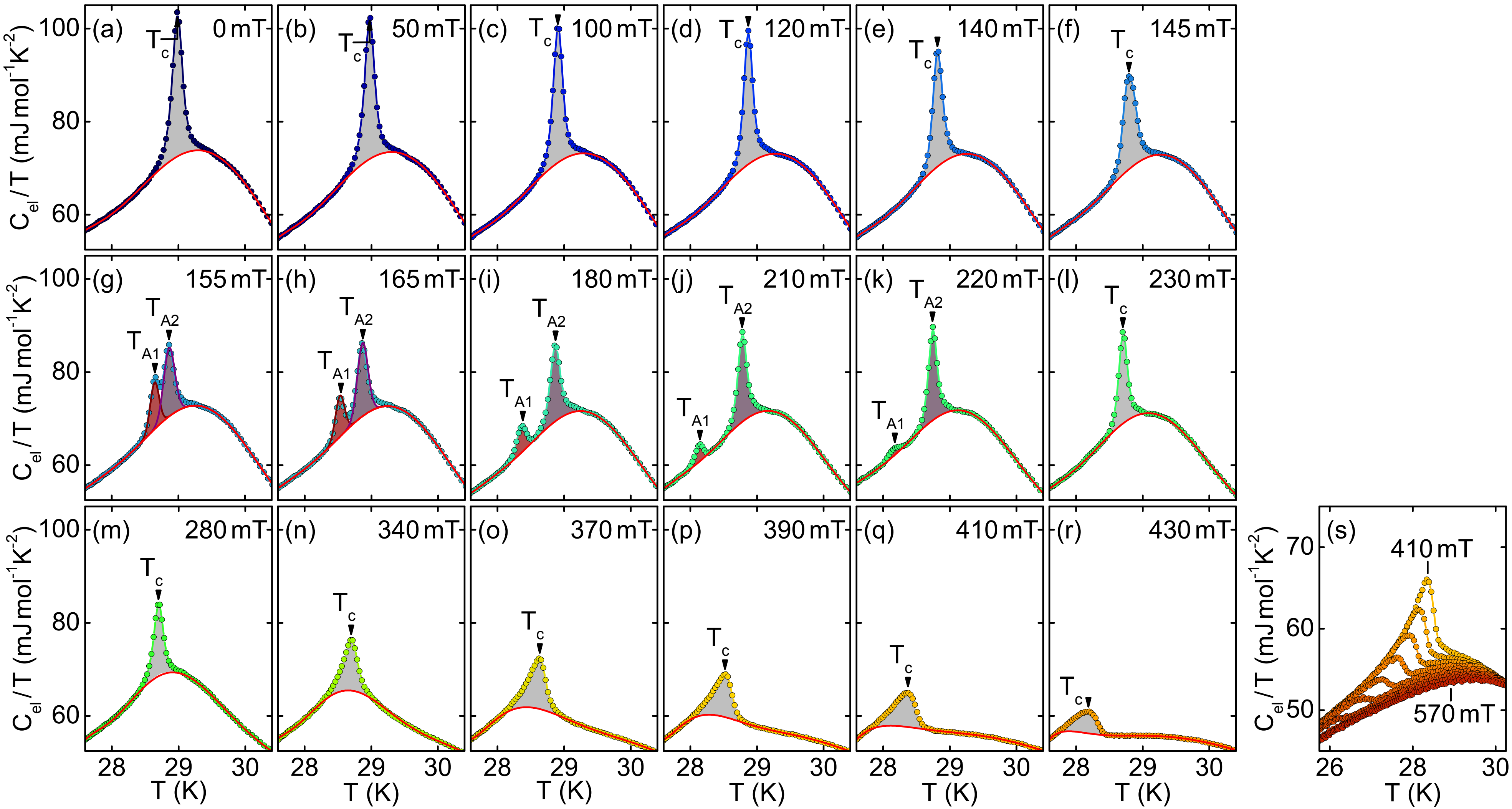
Specific Heat of MnSi



Bauer, Garst, CP, PRL **110**, 177207 (2013)

Specific Heat of MnSi

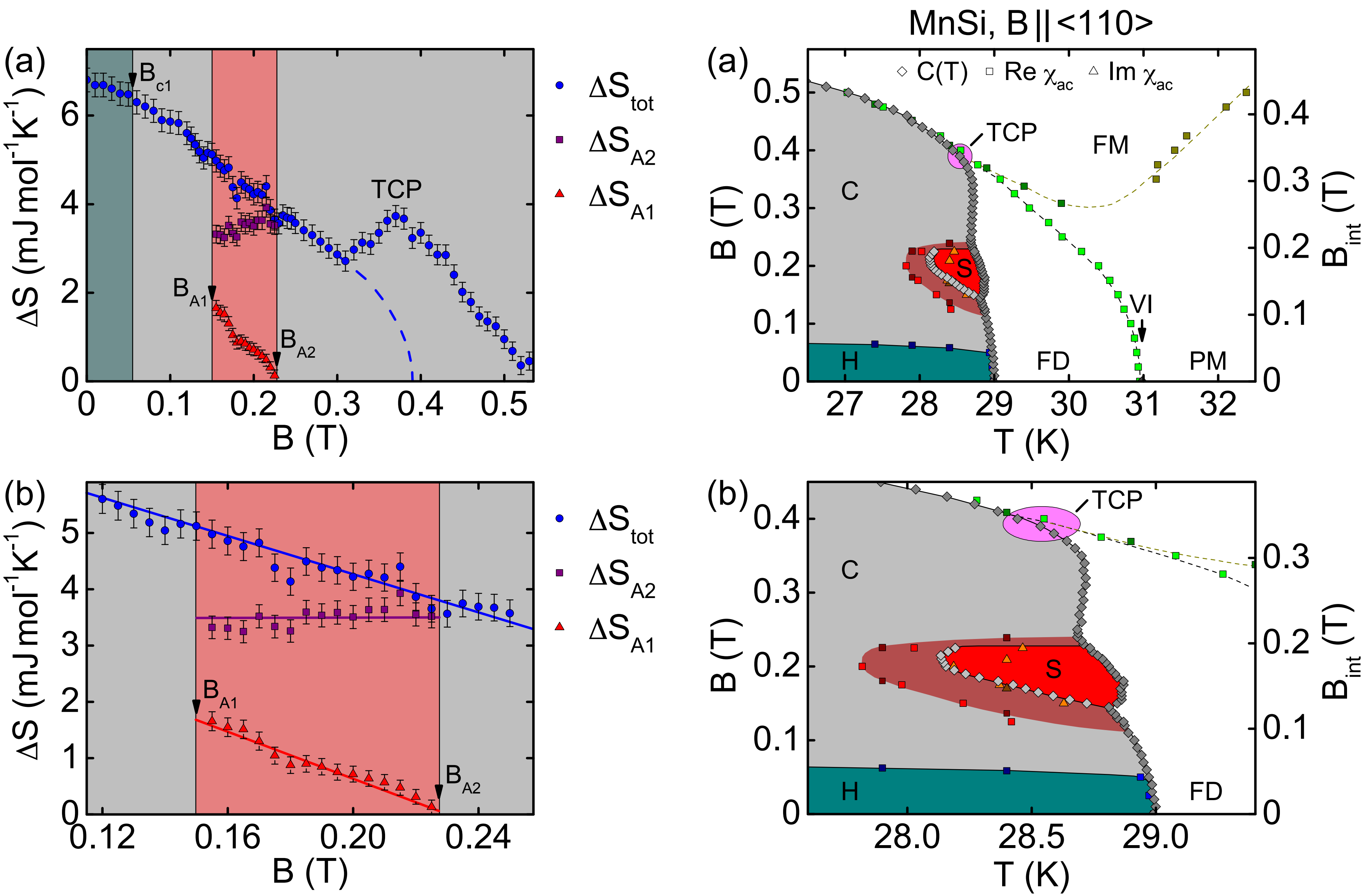
first order transition



second order transition

Bauer, Garst, CP, PRL **110**, 177207 (2013)

Magnetic Phase Diagram of MnSi Revisited

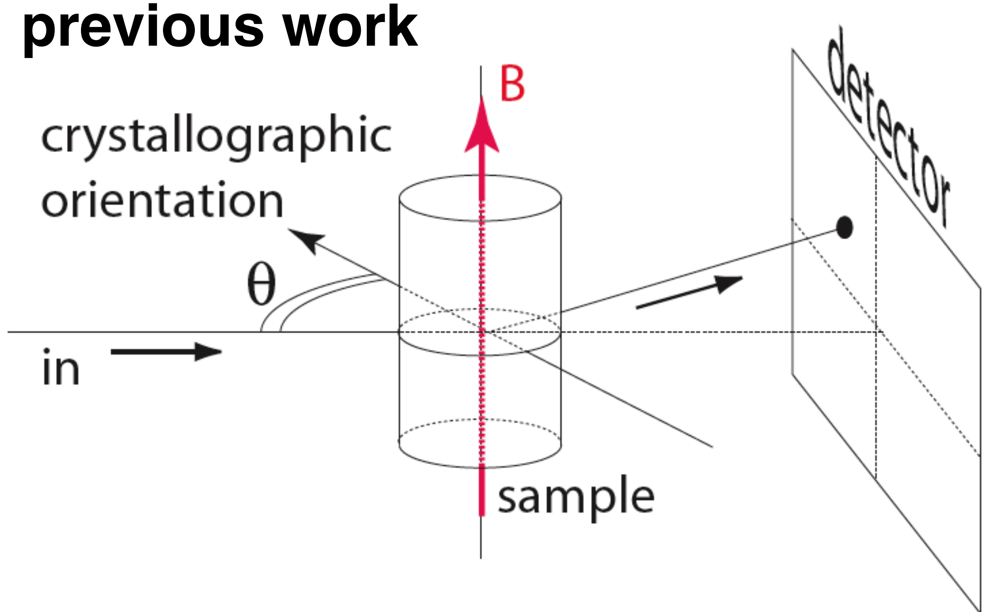


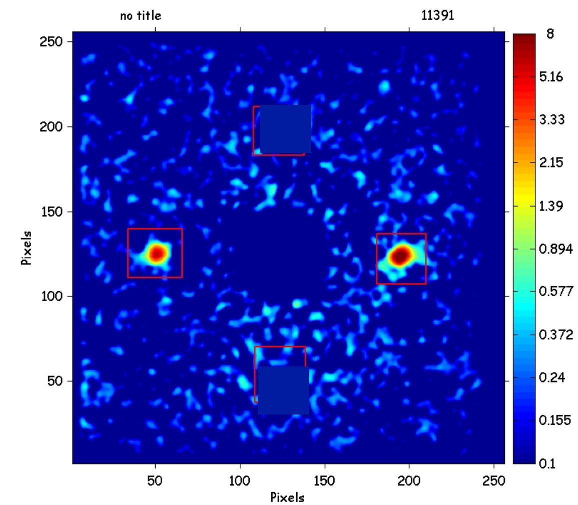
Bauer, Garst, CP, PRL **110**, 177207 (2013)

Nature of the A-Phase

Neutron Scattering Pattern in the A-Phase

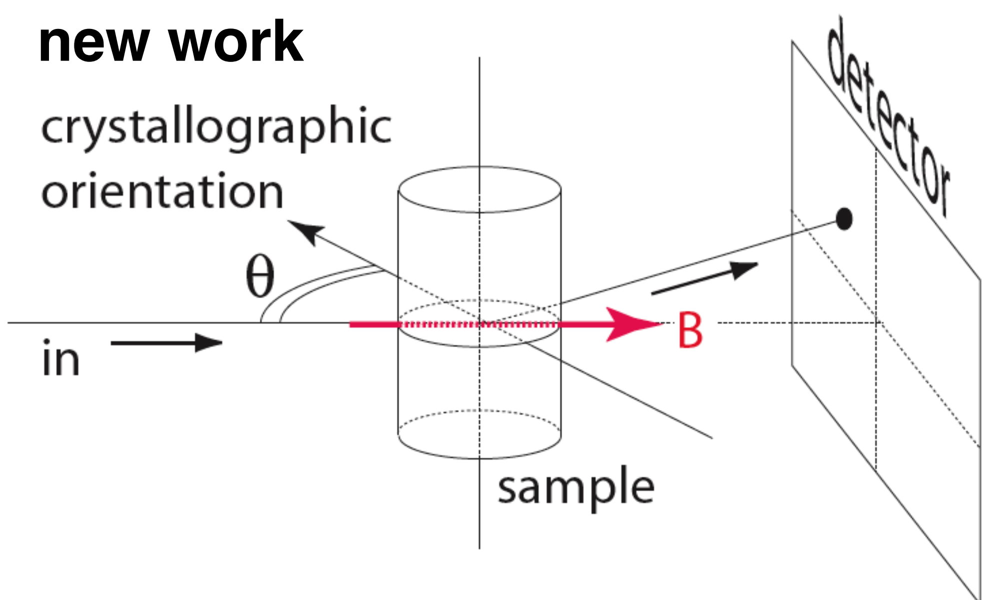
previous work

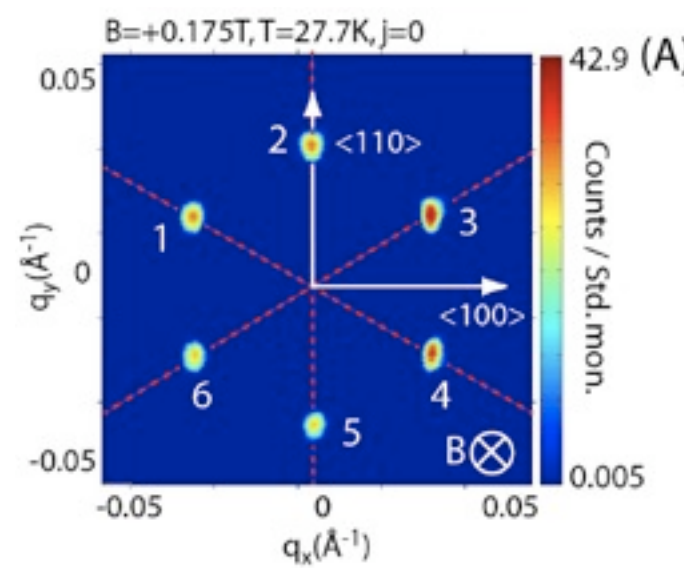




cf. Lebech, Bernhoeft (1993)
Grigoriev, et al. (2006)

new work

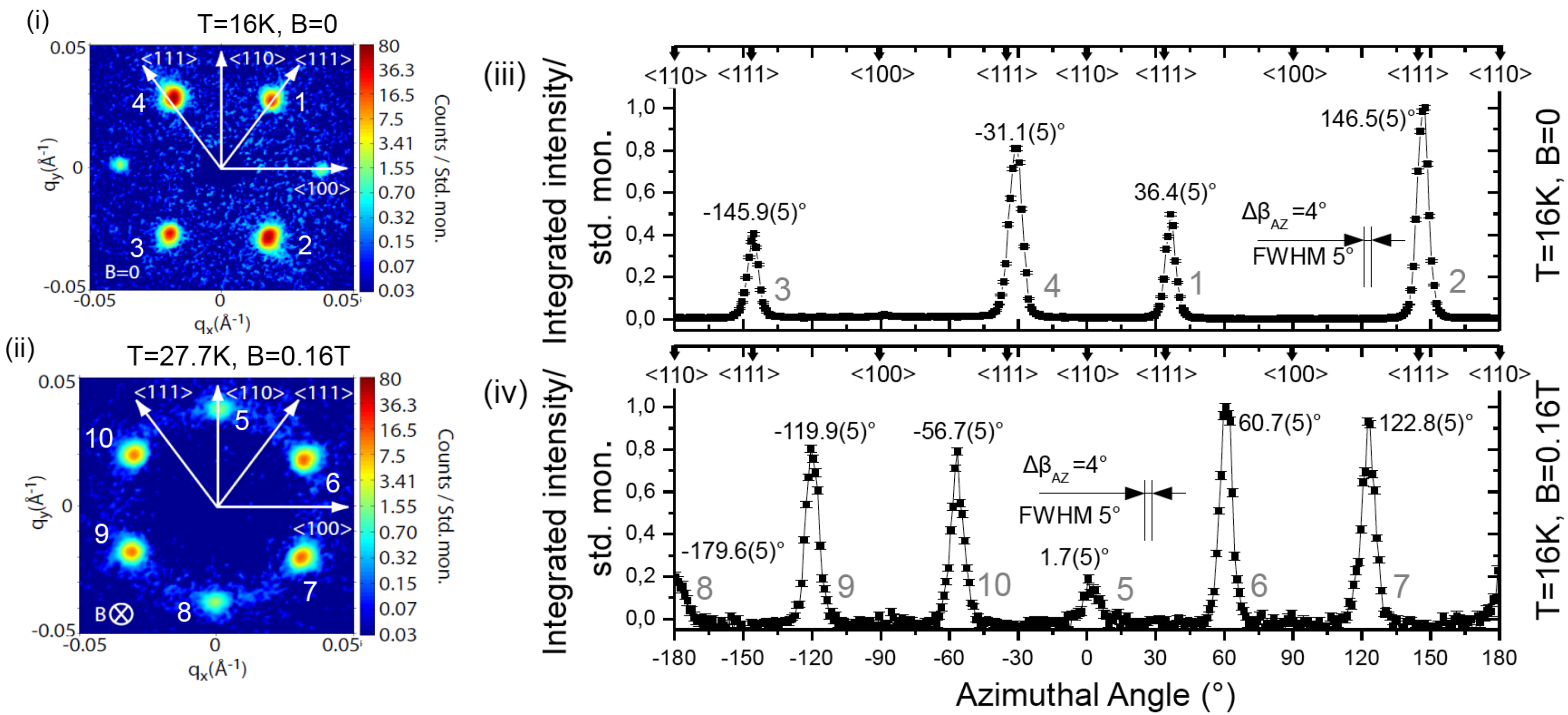




Mühlbauer et al, Science **323**, 915 (2009)

Very Weak Pinning to Crystal Lattice: Neutrons

all measurements at MIRA (FRM II)



Stabilization through anisotropy?

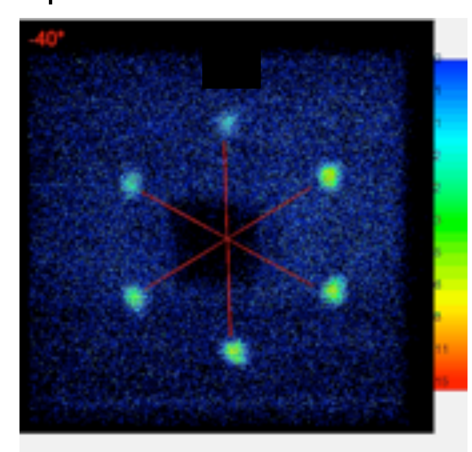
Bogdanov & Yablonskii JETP **68** 101 (1989)

spin order not sensitive to orientation!

MnSi

dependence on orientation

$\theta =$



measurements @ MIRA, FRM II

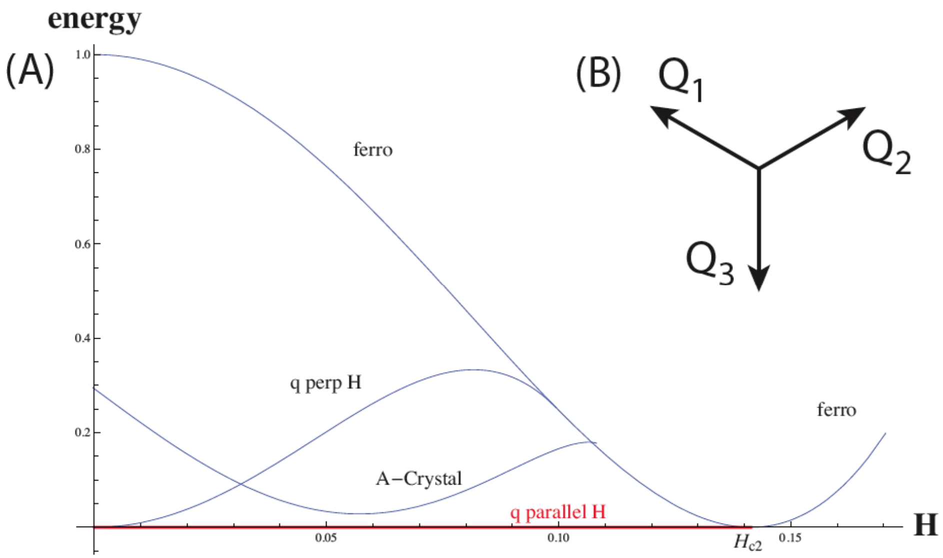
Fluctuation-Stabilized Multi-q Structure

$$F[\mathbf{M}] = \langle r_0 \mathbf{M}^2 + J(\nabla \mathbf{M})^2 + 2D\,\mathbf{M}\cdot(\nabla\times\mathbf{M}) + U\mathbf{M}^4 \rangle$$

$$\propto \langle \mathbf{M}_Q^2\, \mathbf{M}_Q \rangle \cdot \mathbf{m}_0$$

triple-q + uniform M

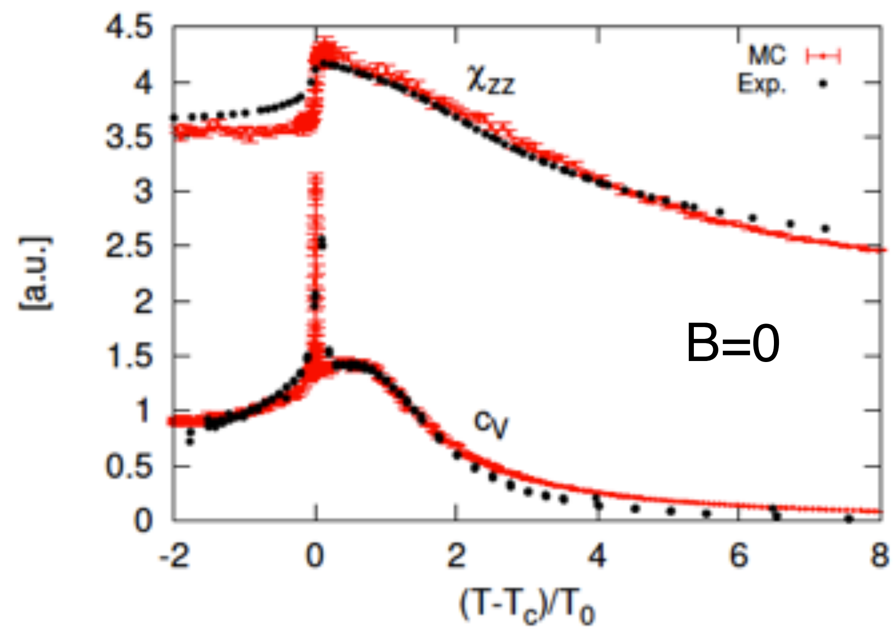
Binz, Vishwanath, Aji PRL (2006)



Mühlbauer, et al. Science **323**, 915 (2009)

perp. single-q: **metastable**
triple-q: **metastable**

Monte-Carlo
(includes fluctuations)



Buhrandt & Fritz, arXiv/1304.6580

Fluctuation-Stabilized Multi-q Structure

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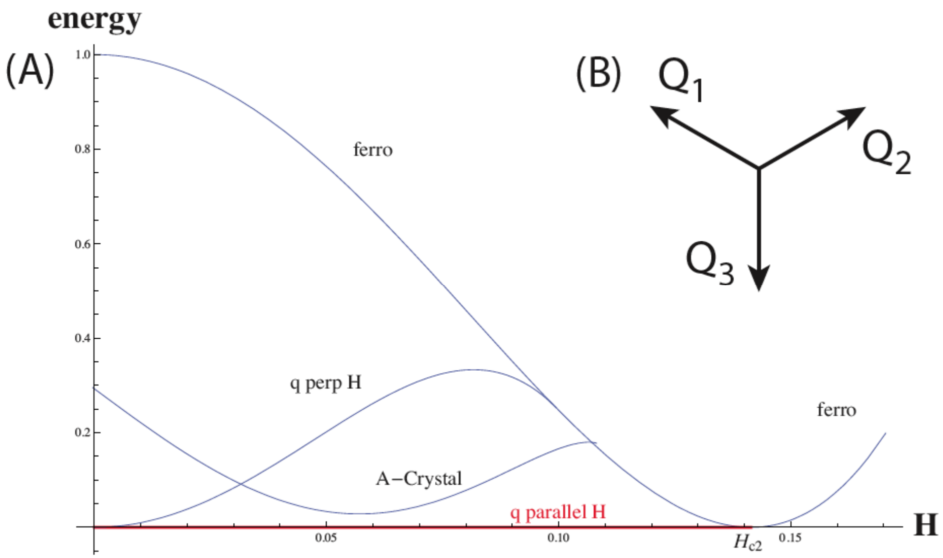

Mühlbauer, et al. Science **323**, 915 (2009)

$$\propto \langle \mathbf{M}_Q^2\, \mathbf{M}_Q \rangle \cdot \mathbf{m}_0$$

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Binz, Vishwanath, Aji PRL (2006)

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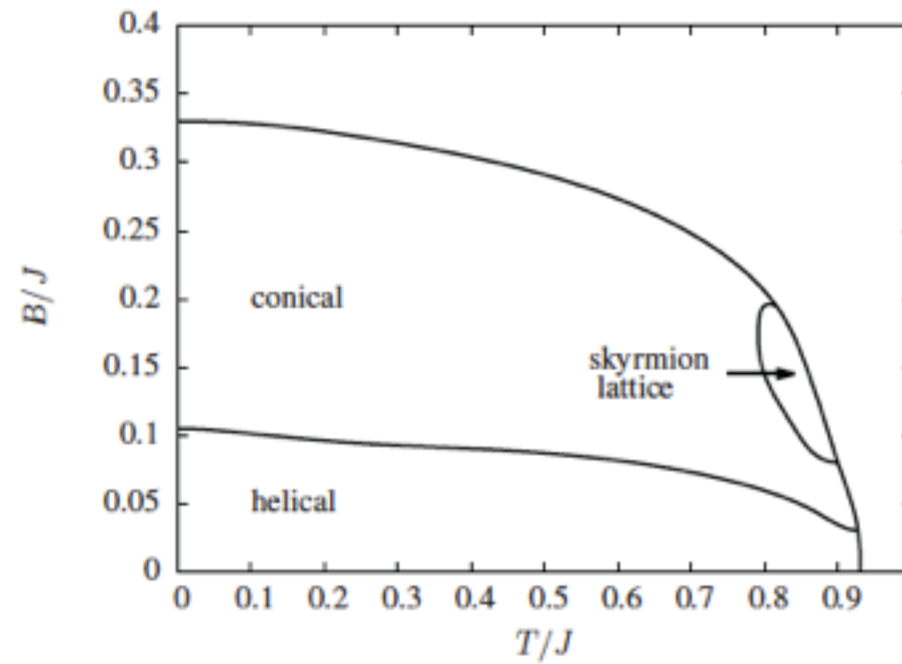
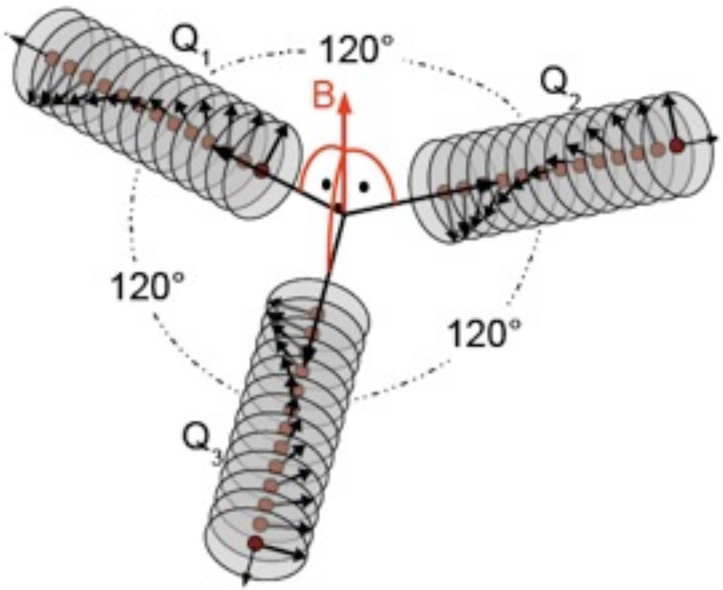
Monte-Carlo
(includes fluctuations)



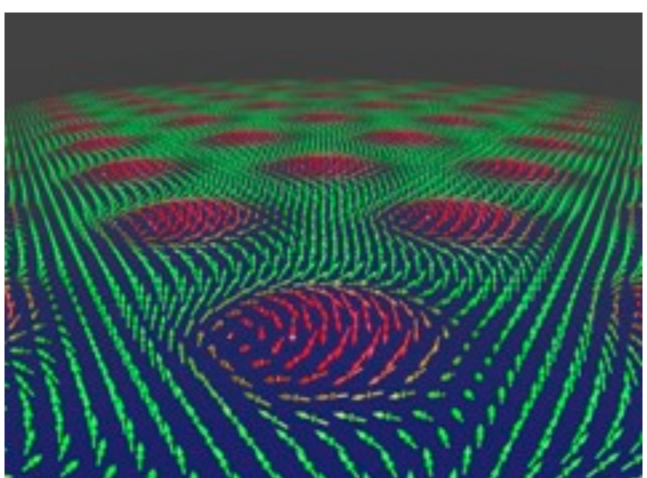
Buhrandt & Fritz, arXiv/1304.6580

Topological Properties of the Rigorous Solution

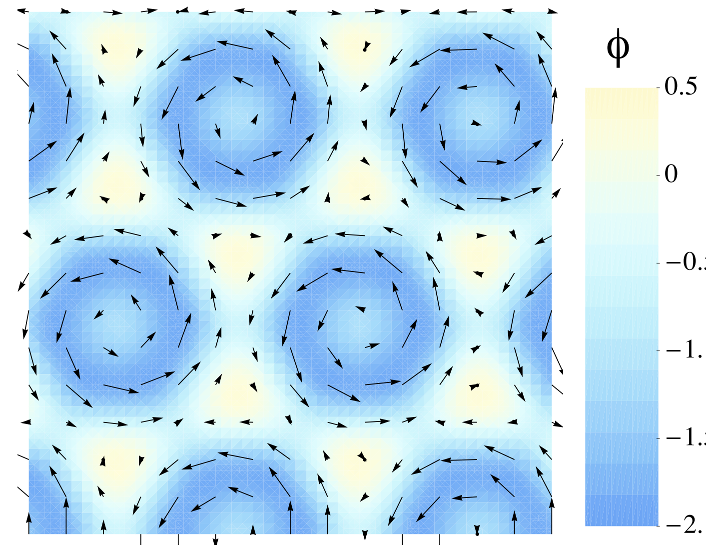
phase btw fundamental modes



center: M antiparallel B



projection from above



$$\phi = \frac{1}{4\pi}\vec{n}\cdot\frac{\partial\vec{n}}{\partial x}\times\frac{\partial\vec{n}}{\partial y}$$

winding number per unit cell:

$$\Phi = -1$$

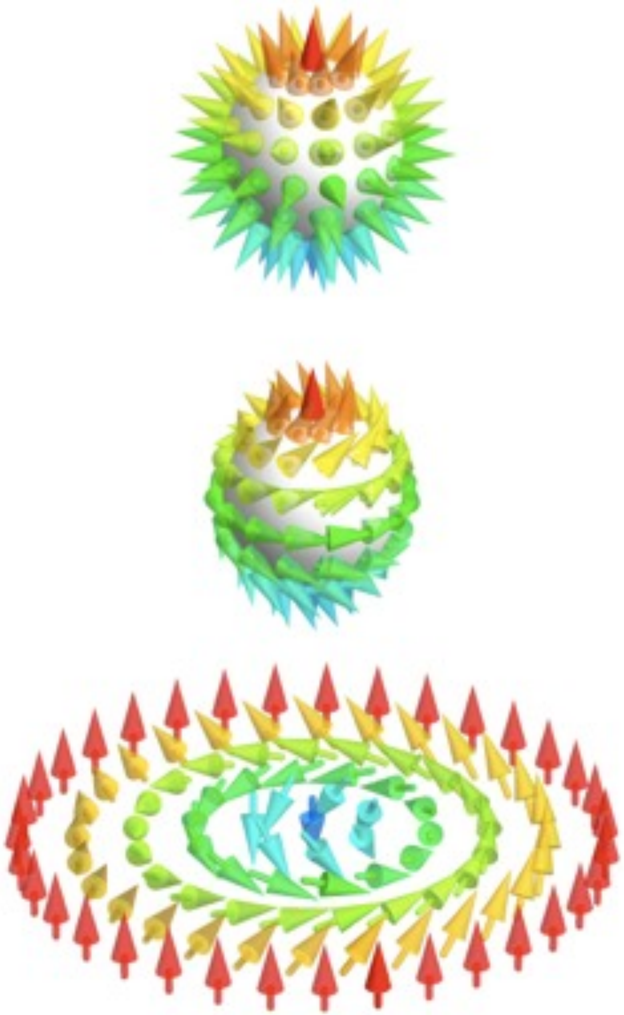
lattice of topological knots

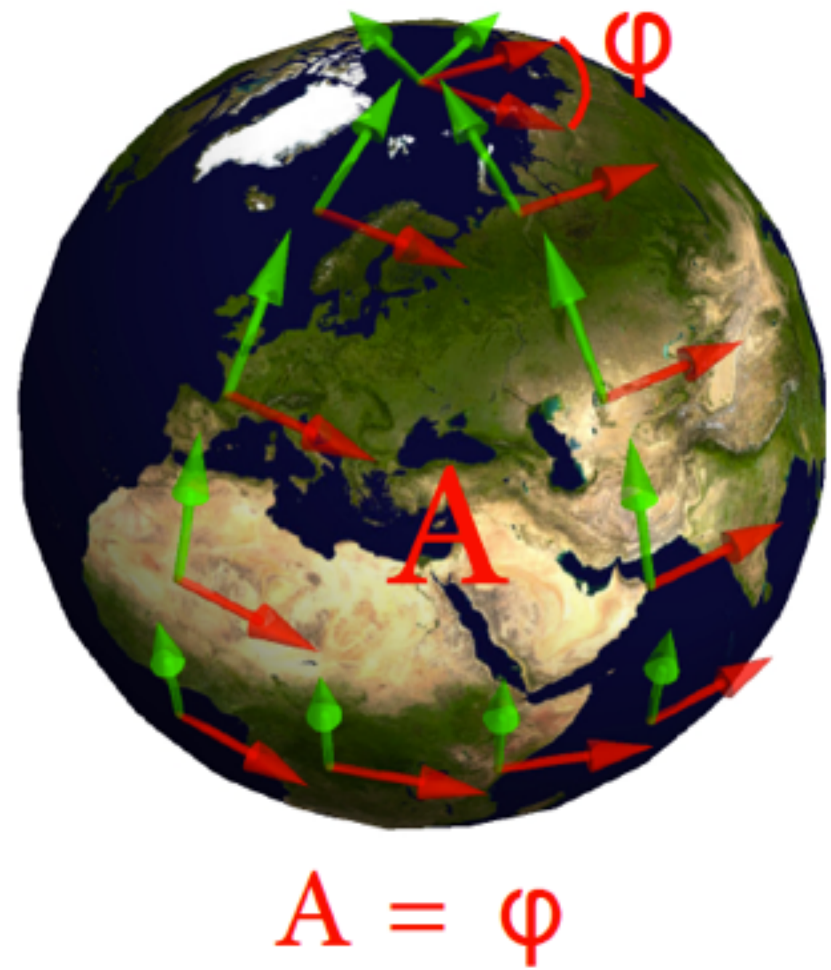
skyrmions

Adams et al., PRL **107**, 217206 (2011)

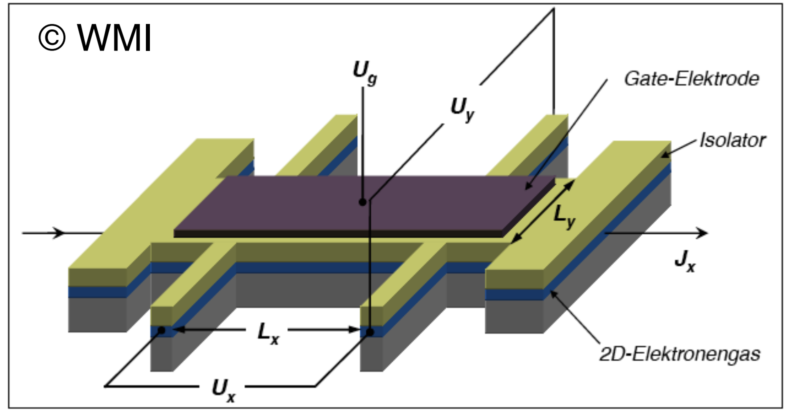
Poor Man‘s Experimental Probe of Topology (emergent magnetic field)

From Topological Winding to Berry's Phase

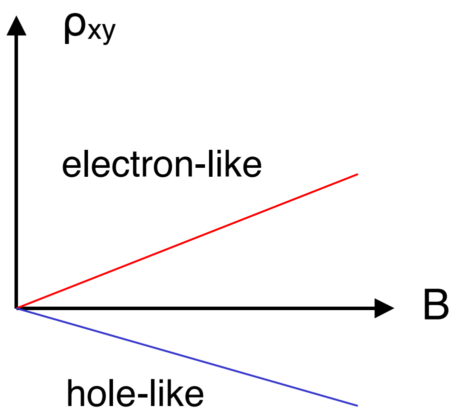




Hall Effects in Magnetic Materials

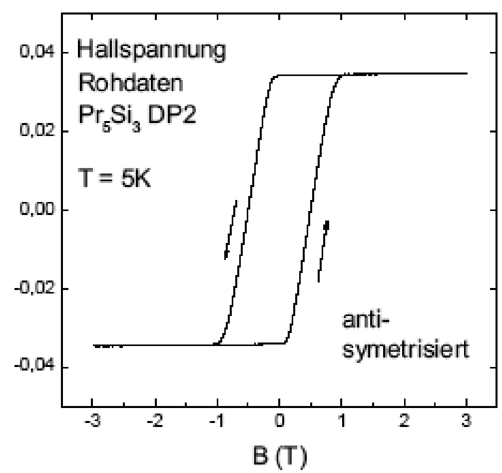


normal HE



$$\rho_{xy} = R_0 B$$

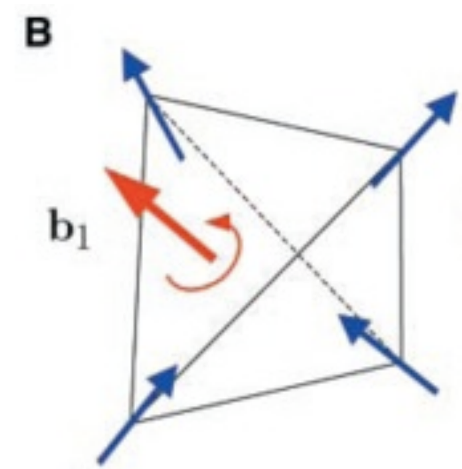
anomalous HE



Berry phase (momentum space)

$$\rho_{yx} = R_0 B + S_H \rho^2 M$$

topological HE



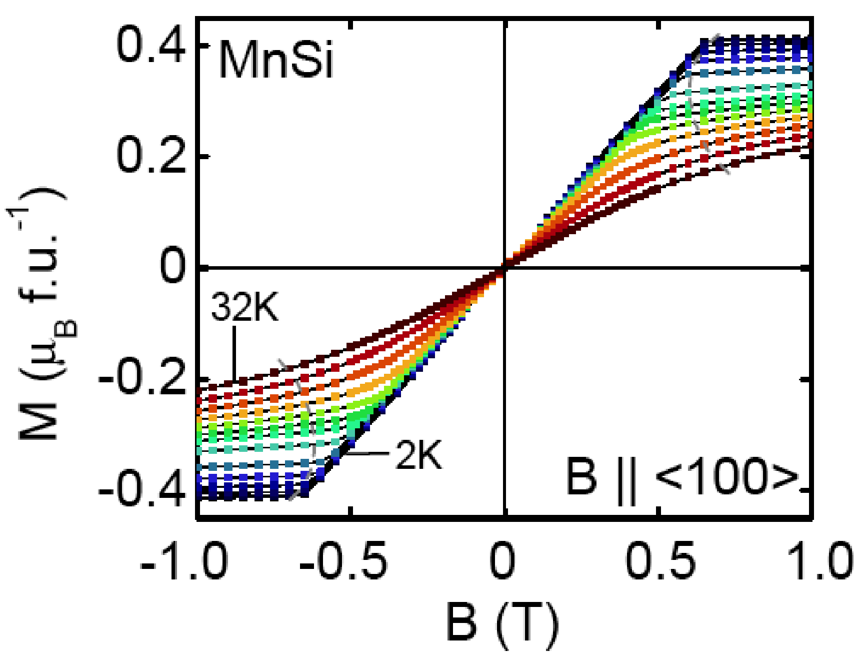
Berry phase (real space)

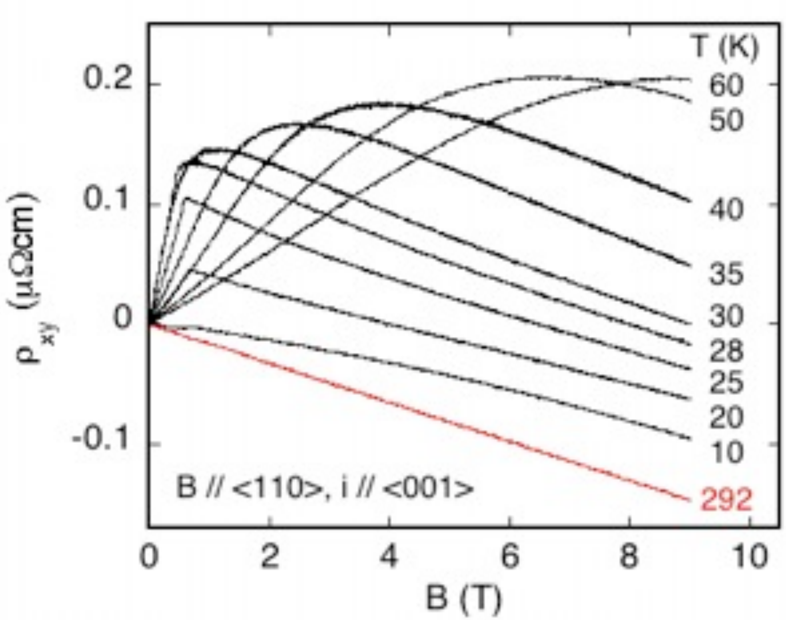
$$\Delta\rho_{xy} \approx P\, R_0\, B^z_{\mathrm{eff}}$$

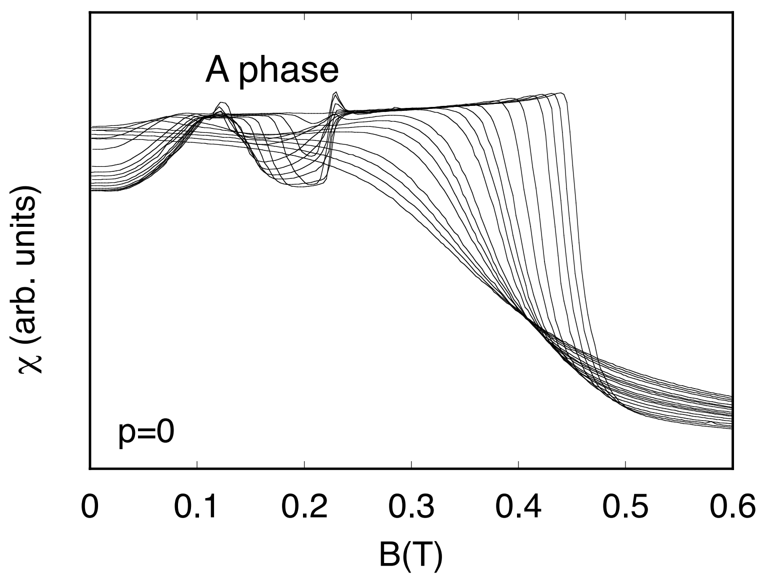
$$\vec{B}_{\mathrm{eff}} = \Phi_0\, \vec{\Phi}$$

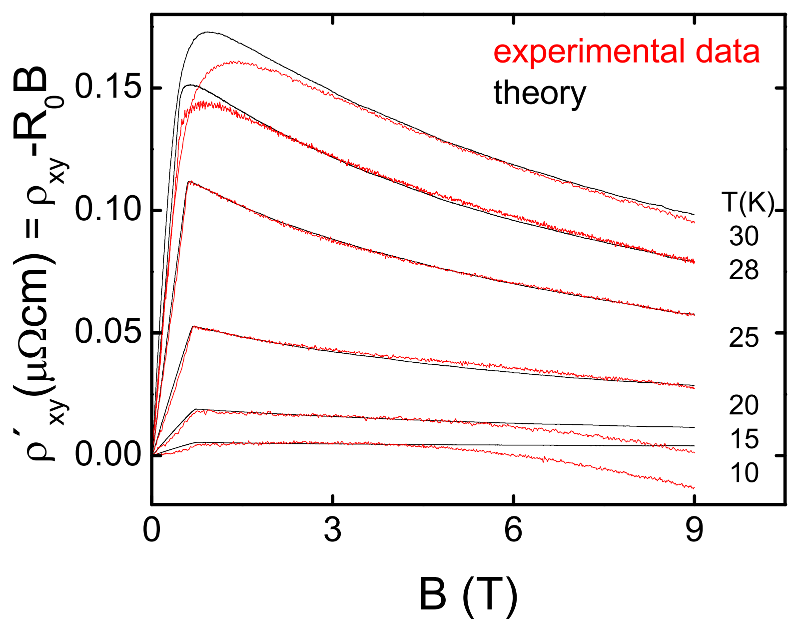
cf Nagaosa et al.,
RMP **82**, 1539 (2010)

Anomalous Hall Effect in MnSi



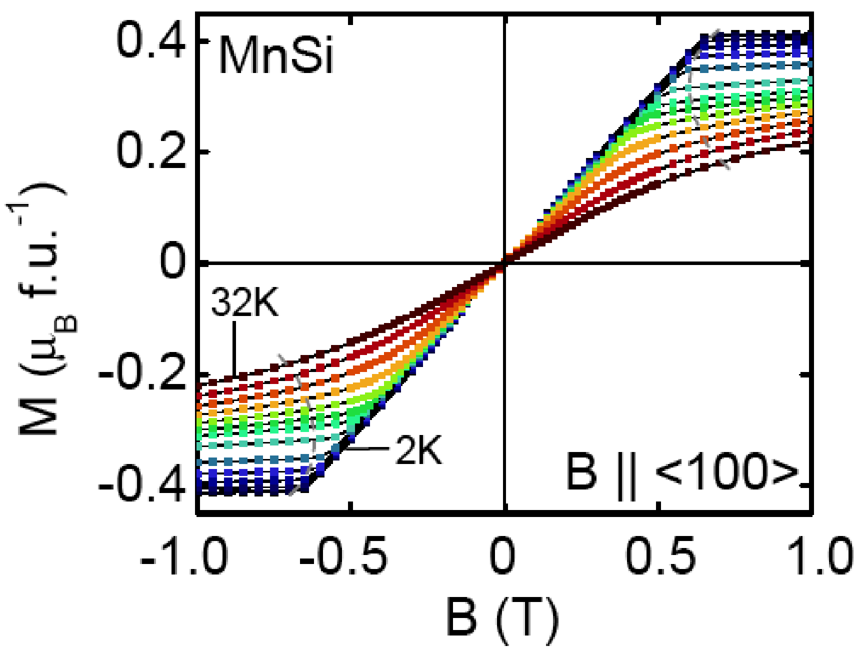


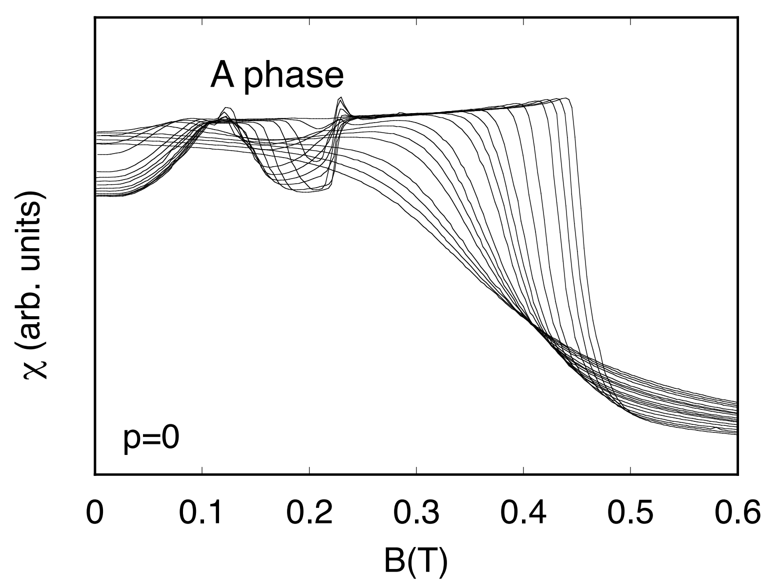


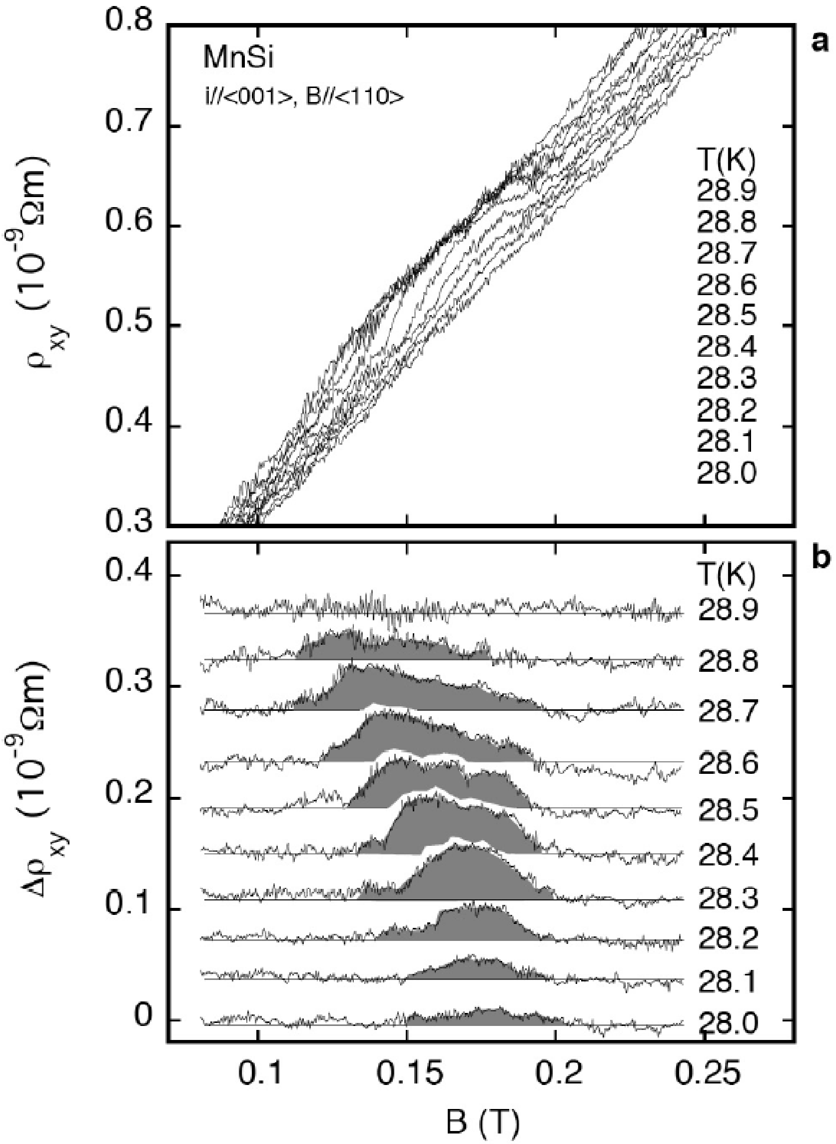


Lee et al. PRB **75**, 172403 (2007)
see also Neubauer et al., Physica B (2009)

Anomalous Hall Effect in MnSi



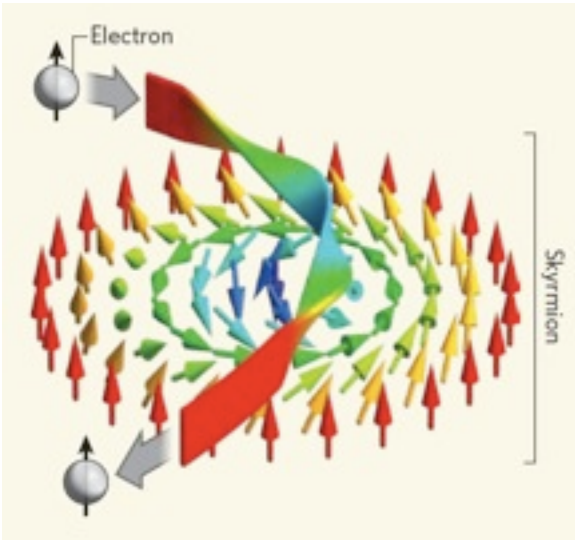


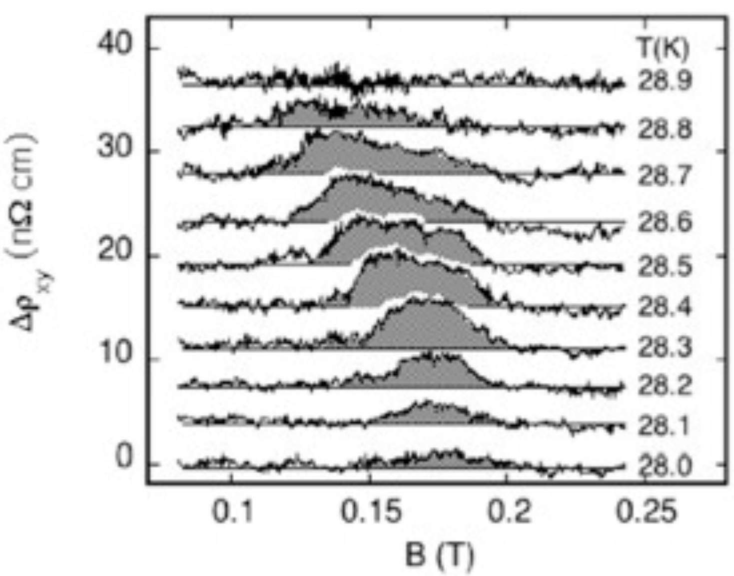


Neubauer et al., PRL **102** 186602 (2009)

Emergent Magnetic Field of Skyrmions

Pfleiderer, Rosch Nature (N&V) **465** 880 (2010)





conduction electron tracks spin structure:

- collect Berry phase
- express as Aharonov-Bohm phase
- represents effective field

$$\vec{B}_{\text{eff}} = \Phi_0 \, \vec{\Phi}$$

$$\Phi_0 = h/e$$

$$\Phi^\mu = \frac{1}{8\pi} \epsilon_{\mu\nu\lambda} \hat{n} \cdot (\partial_\nu \hat{n} \times \partial_\lambda \hat{n})$$

trivial topology: $\Phi = 0$

non-trivial topology: $\Phi = -1$

$\vec{B}_{\text{eff}} \approx$ -13 T

Binz, Vishwanath Physica B **403** 1336 (2008)

Neubauer, et al. PRL **102** 186602 (2009)

cf giant emergent fields in MnGe

Kanazawa et al., PRL **106** 156603 (2011)

Topological Unwinding of a Skyrmion Lattice by Magnetic Monopoles

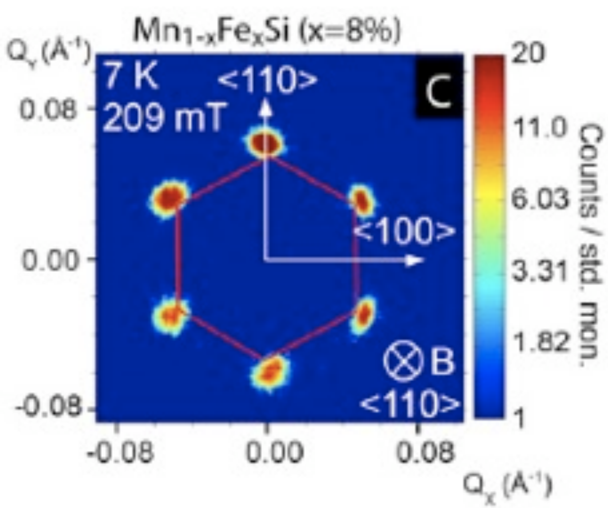
Skyrmion Lattices in B20 Compounds

MnSi
pure metal

Mühlbauer, et al. Science **323**, 915 (2009)
Neubauer, et al. PRL **102** 186602 (2009)
Janoschek, et al. J. Phys. Conf. Series (2010)

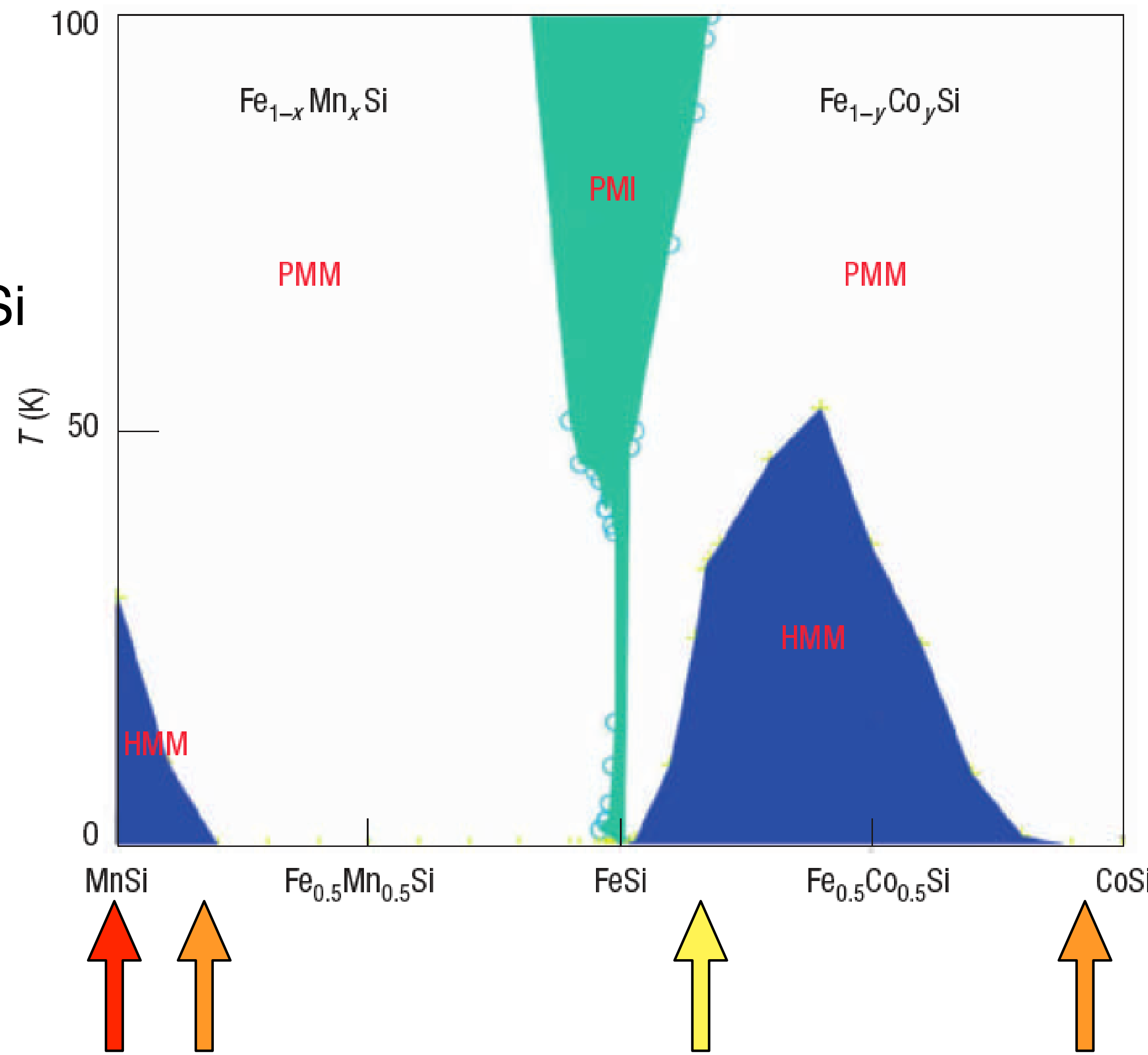
$Mn_{1-x}Fe_xSi$, $Mn_{1-x}Co_xSi$
quantum criticality

Bauer, et al. PRB **82** 064404 (2010)



$Fe_{1-x}Co_xSi$
semiconductor

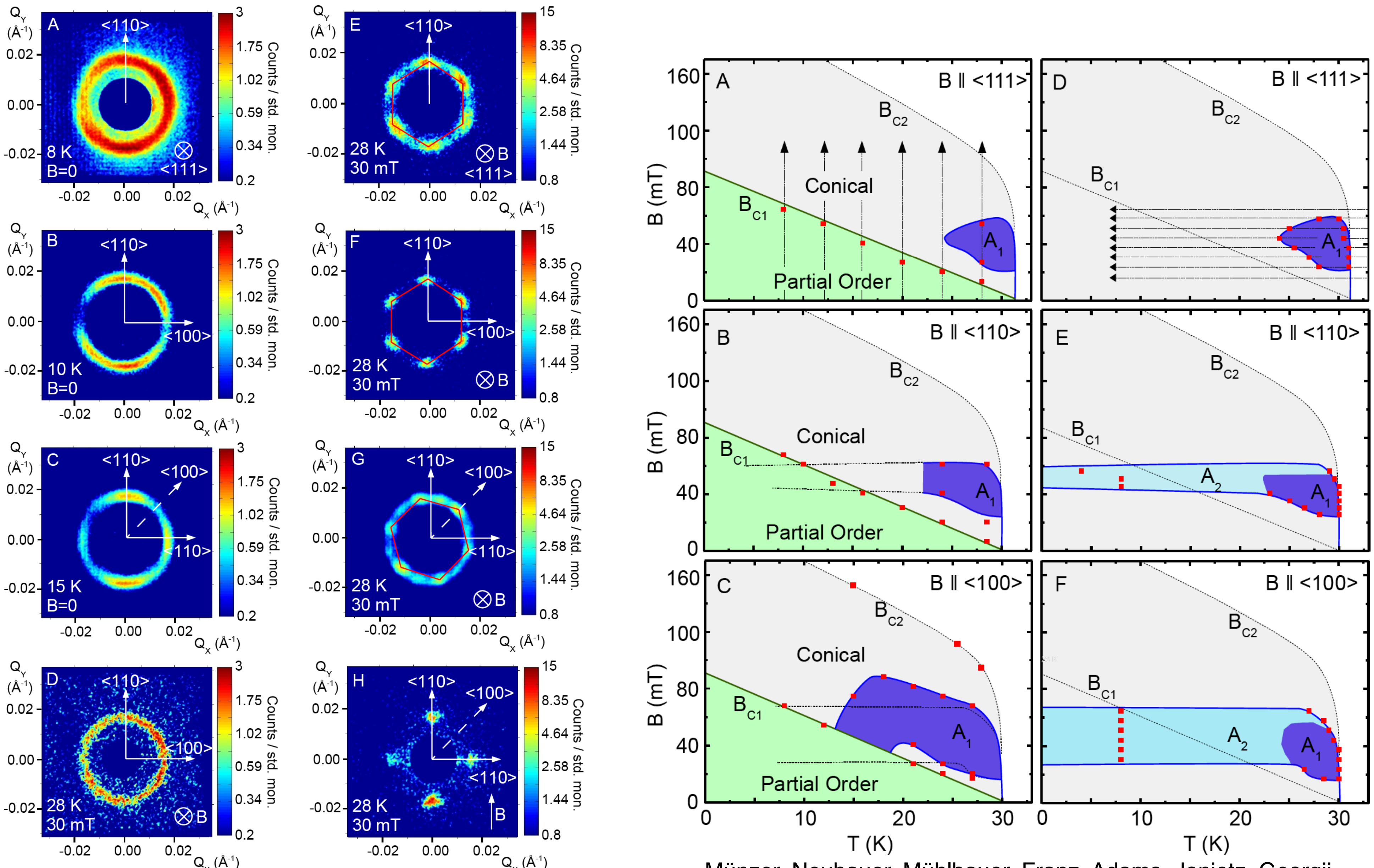
Münzer, et al. PRB(R) **81** 041203 (2010)
Adams, et al. J. Phys. Conf. Series (2010)



plot taken from Manyala et al., Nature Materials (2004)

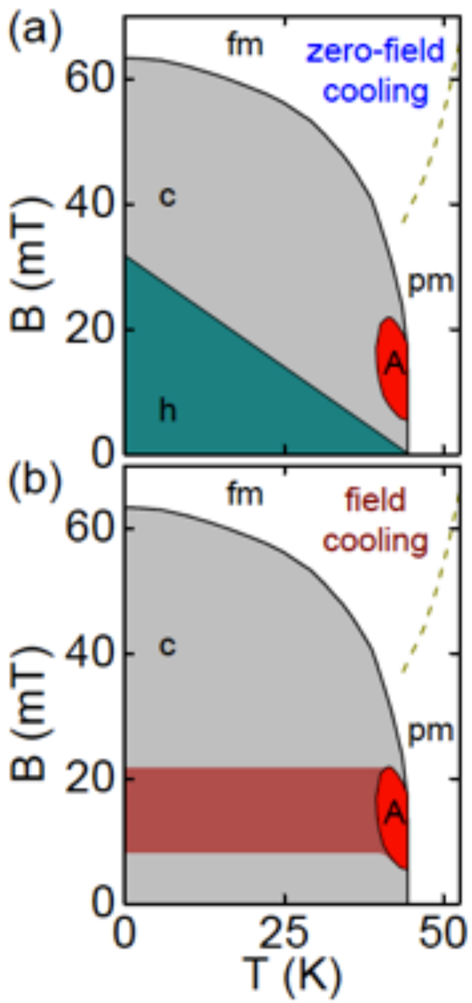
CP et al., J. Phys.: Cond. Matter **82** 064404 (2010)

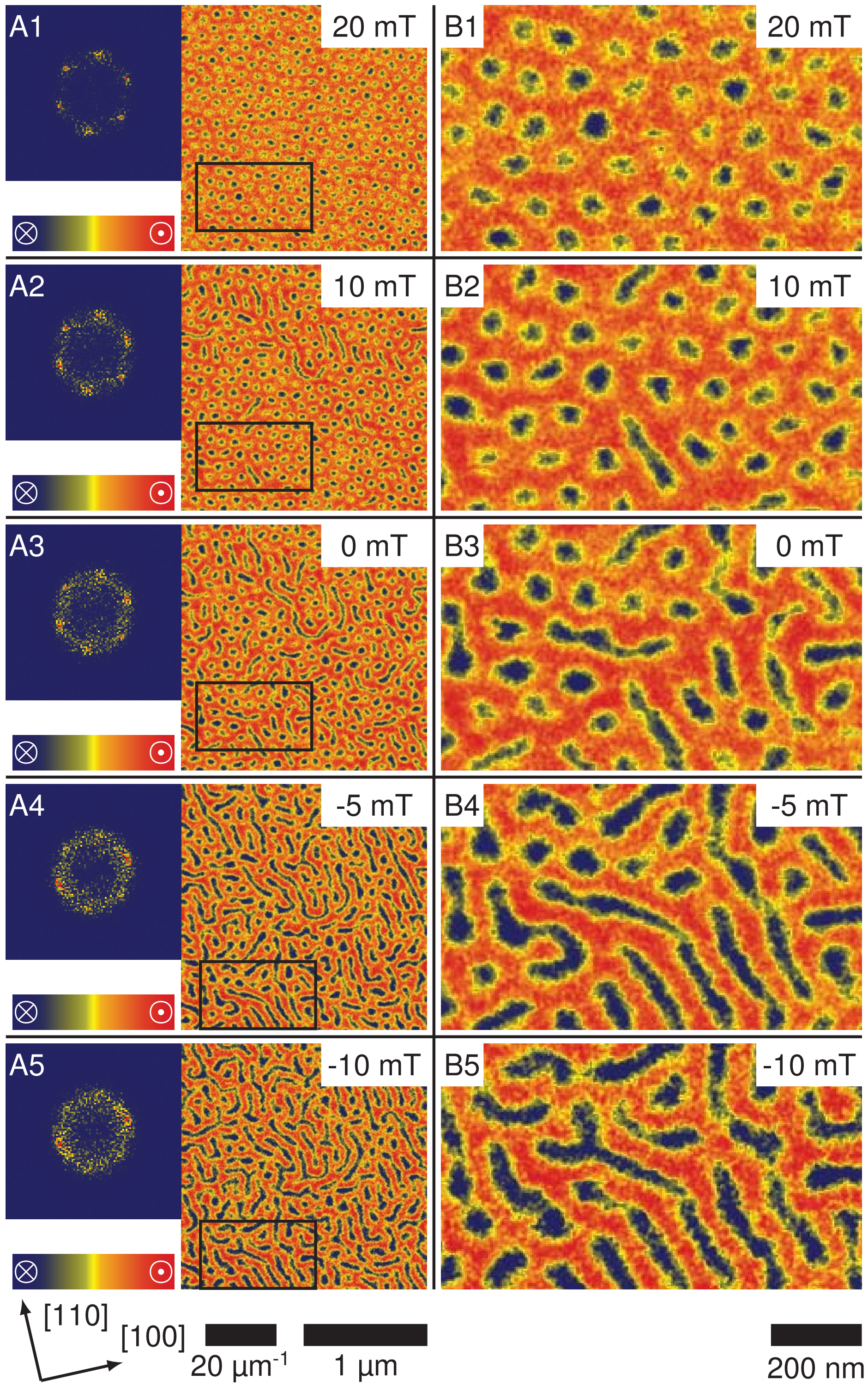
Metastable Skyrmion Lattice in $Fe_{1-x}Co_xSi$



Münzer, Neubauer, Mühlbauer, Franz, Adams, Jonietz, Georgii,
Böni, Pedersen, Schmidt, Rosch, Pfleiderer, PRB(R) **81** 041203 (2010)

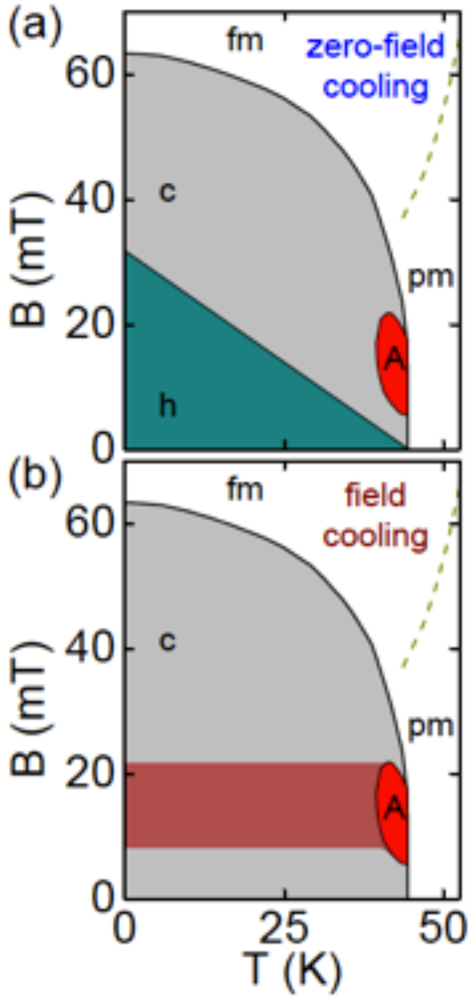
Magnetic Force Microscopy



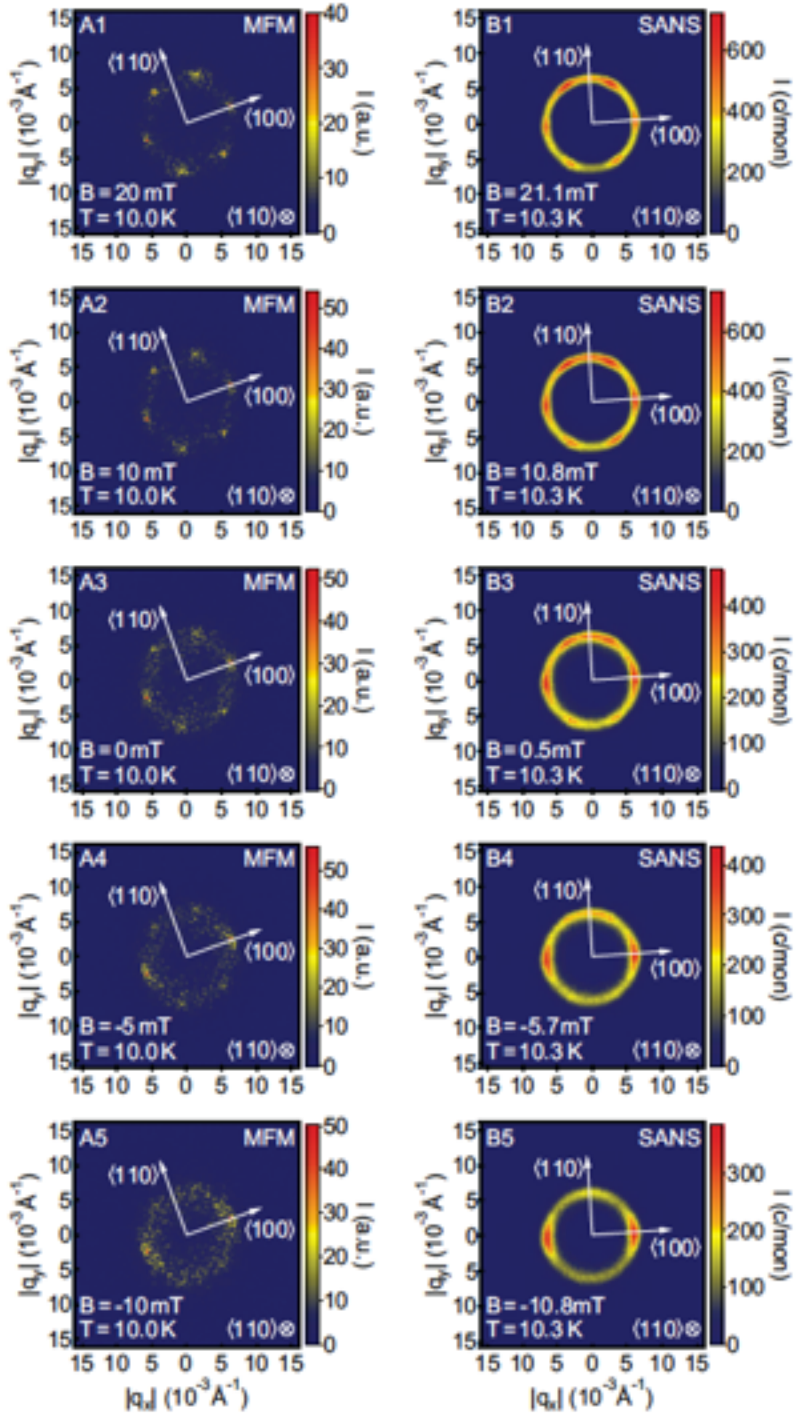


Milde et al, Science **340**, 1076 (2013)

Magnetic Force Microscopy

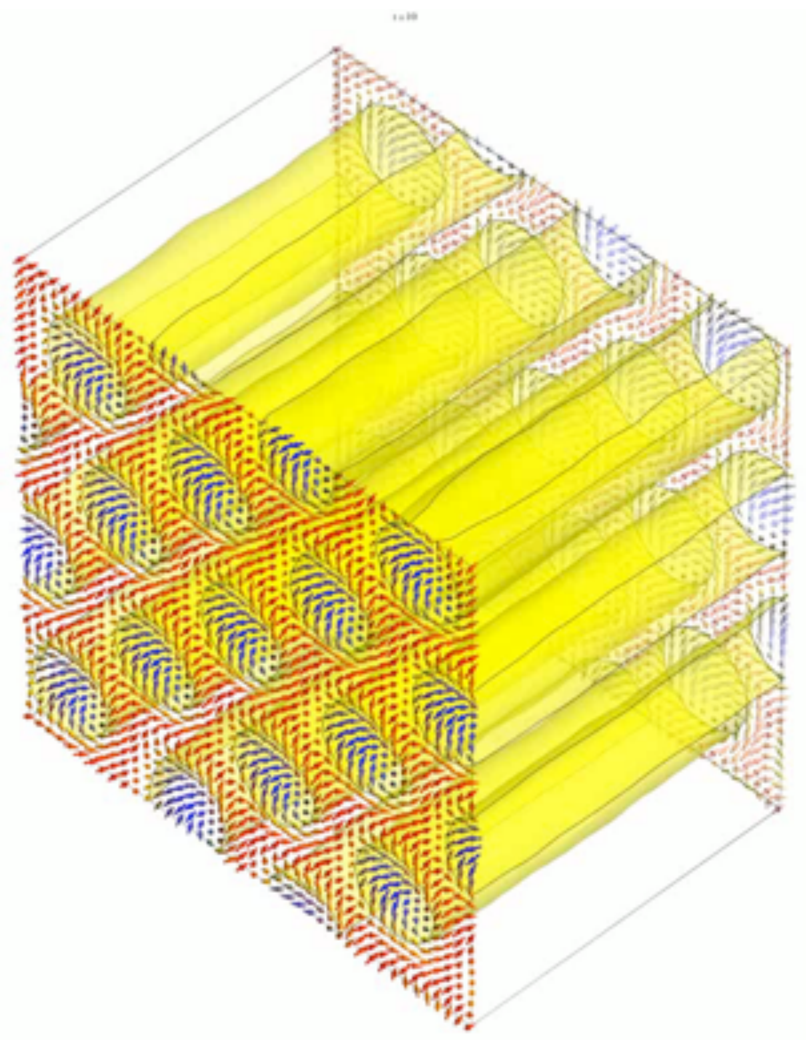


MFM SANS

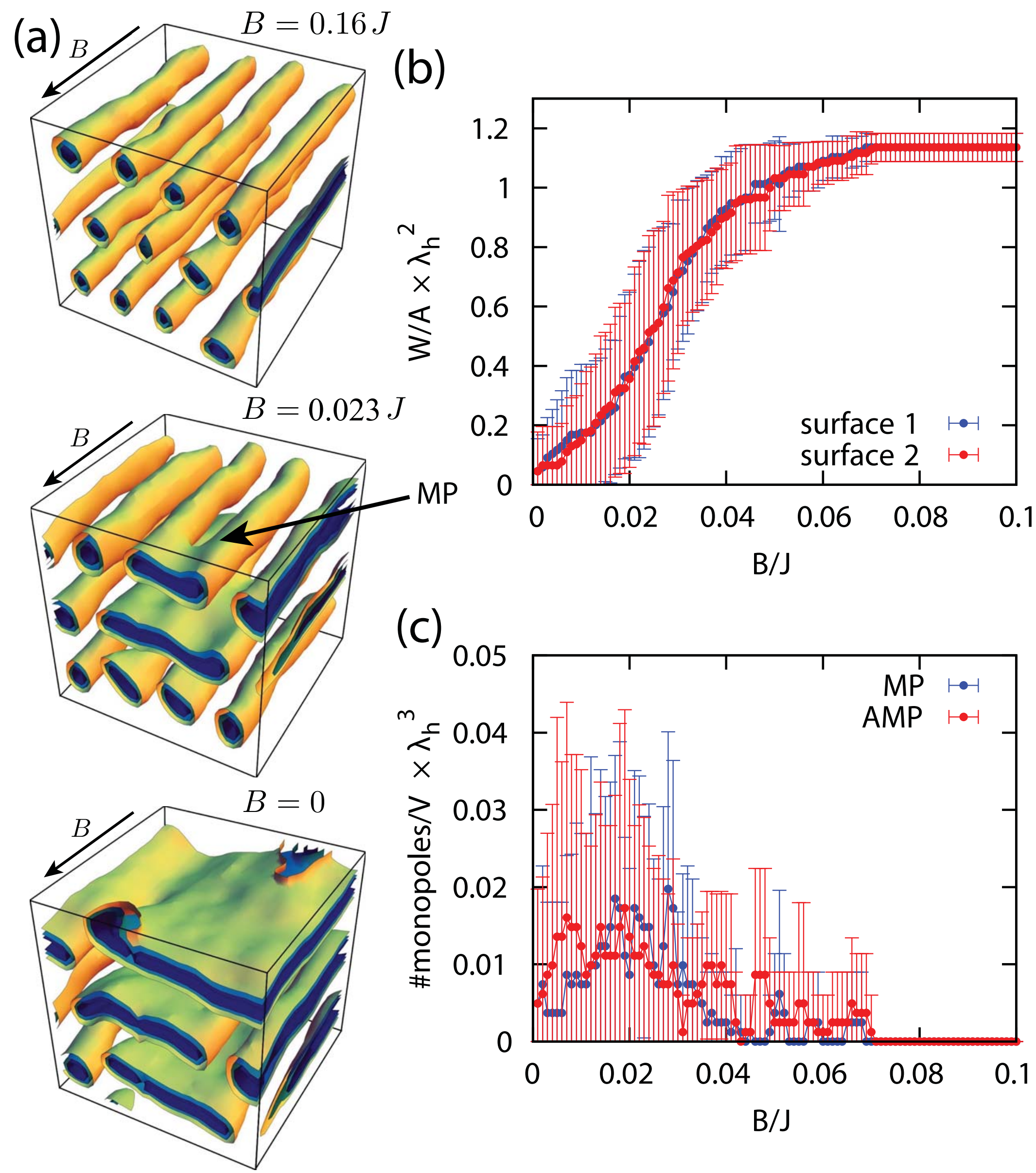


Milde et al, Science **340**, 1076 (2013)

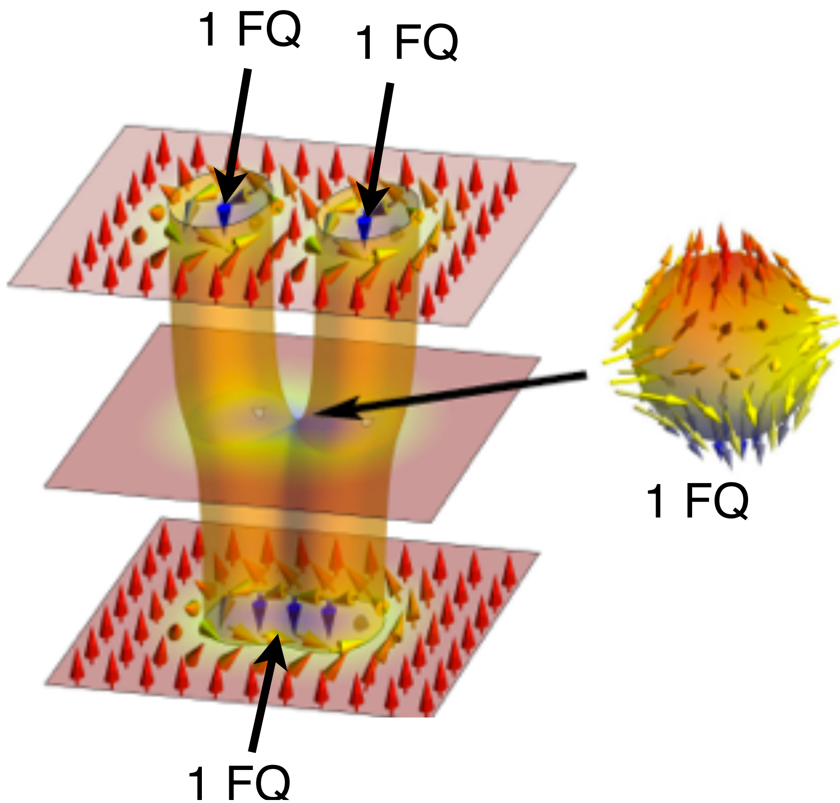
Monte Carlo Simulations in the Metastable Regime



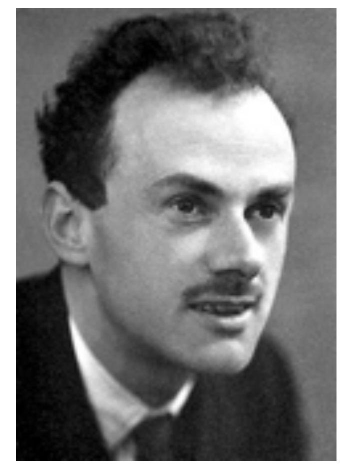
animation C. Schütte

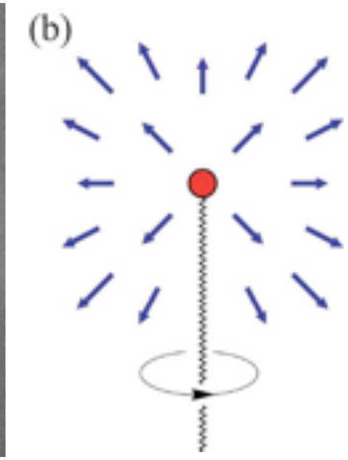


Topological Unwinding of Skyrmions by means of Magnetic Monopoles



$$\oint_{\partial\Omega} \mathbf{B}^e d\sigma = \int_{\Omega} \nabla \mathbf{B}^e d\mathbf{r}$$
$$= -\frac{2\pi}{|q^e|}(N^s_{\text{out}} - N^s_{\text{in}}) = \mp\Phi_0$$





Paul Dirac

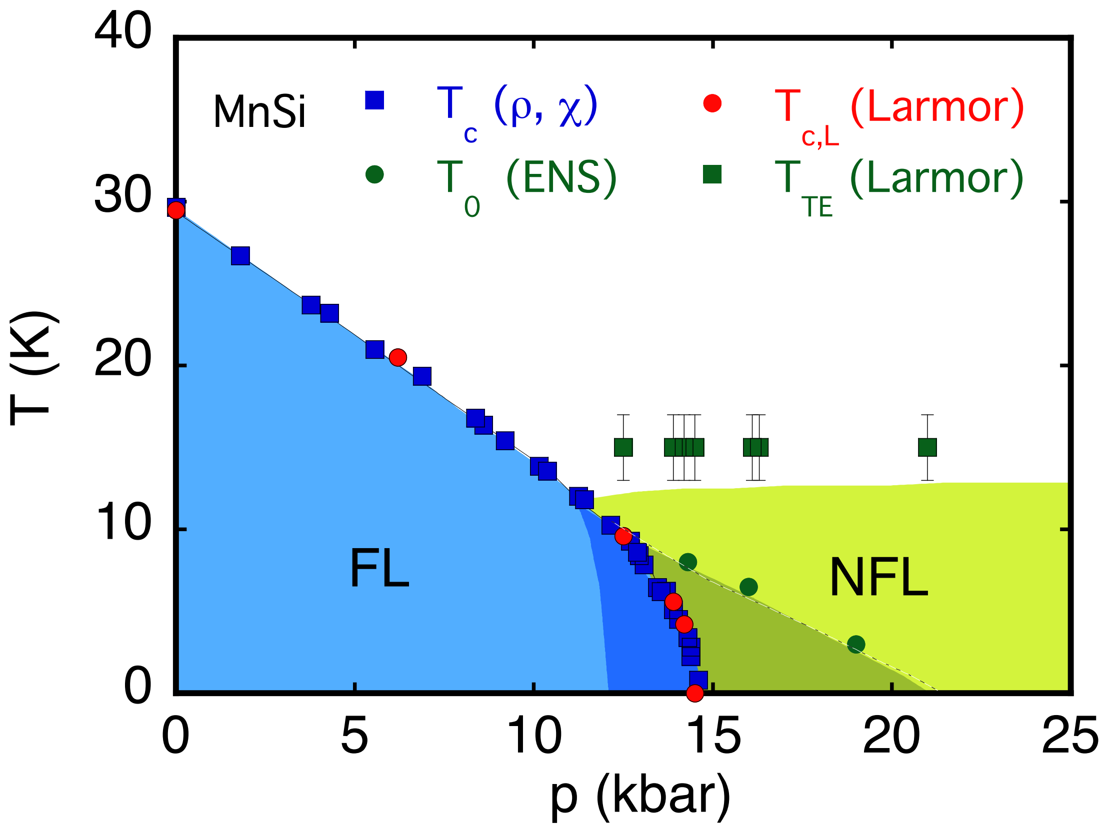
prediction of magnetic monopoles
to explain **quantized** electric charge

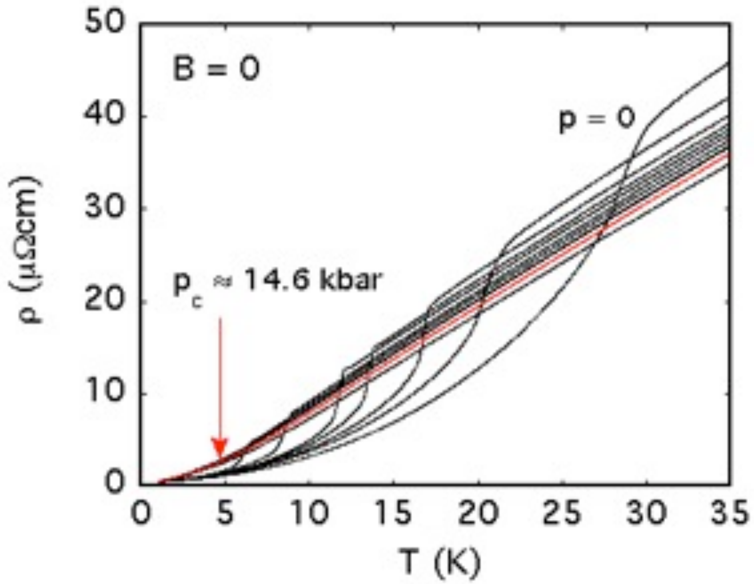
defects in (emergent) B-field with **quantized** charge

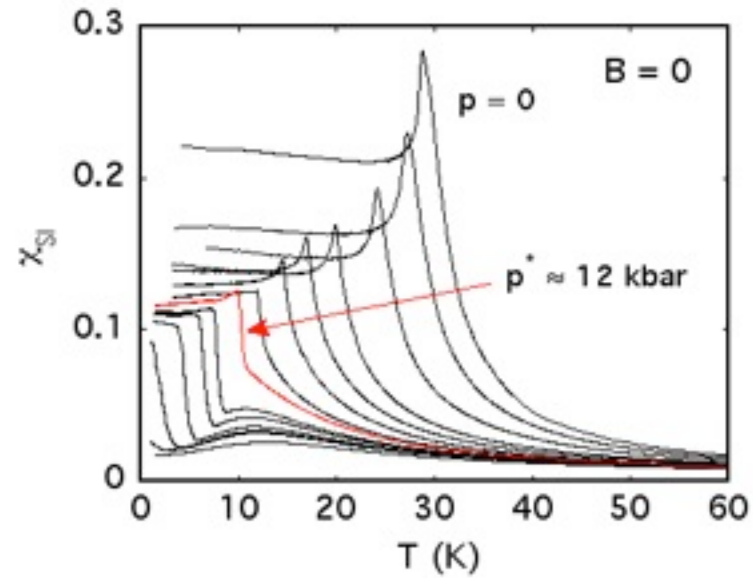
Formation of a Topological Non-Fermi Liquid

Non-Fermi Liquid Puzzle in MnSi Revisited

Magnetic Quantum Phase Transition in MnSi

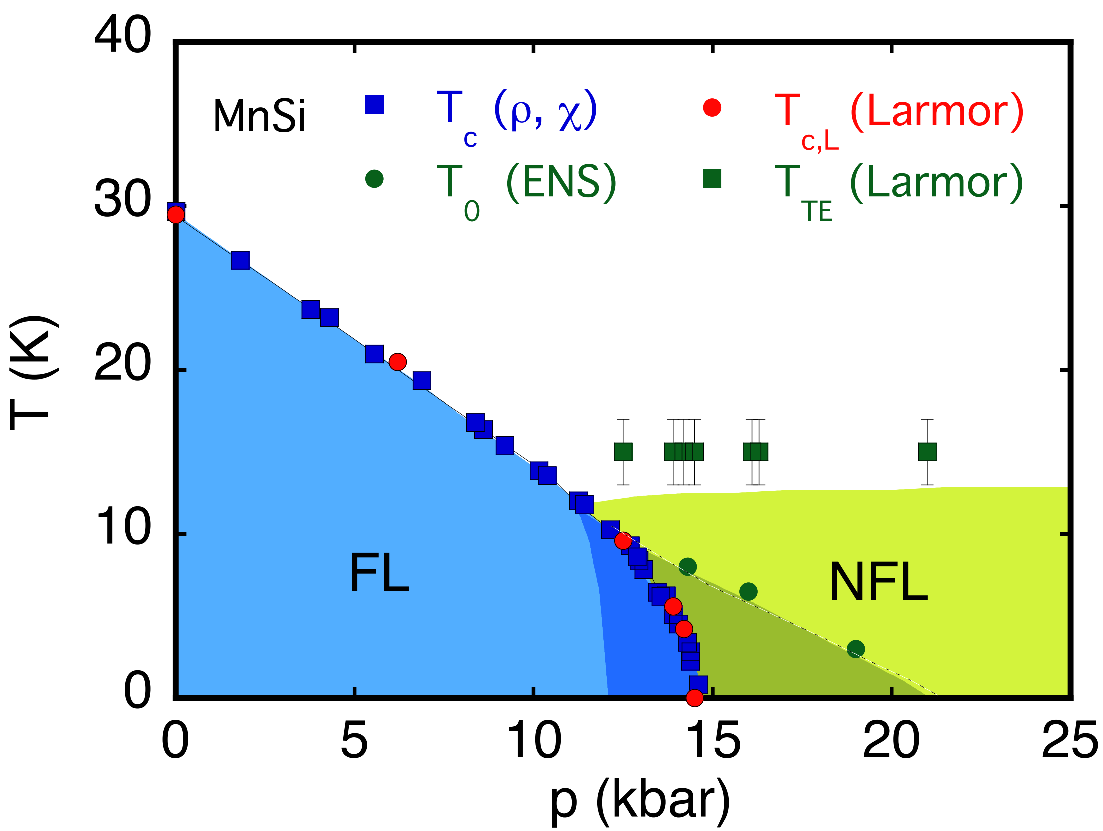


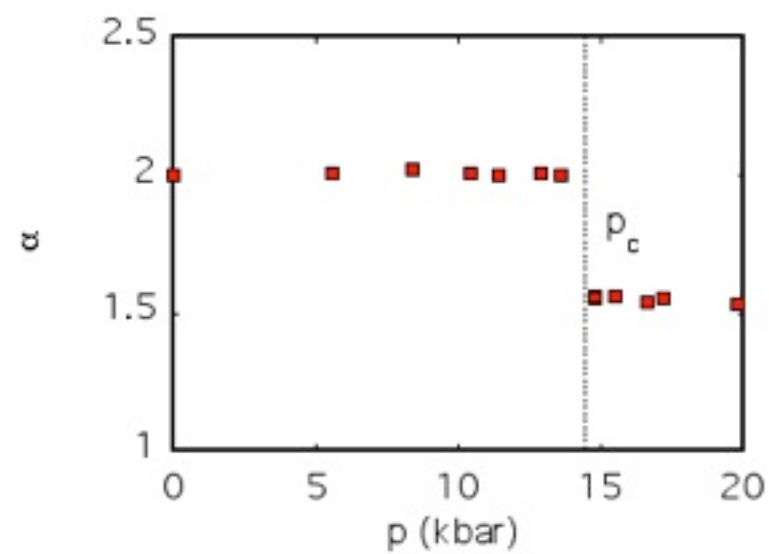


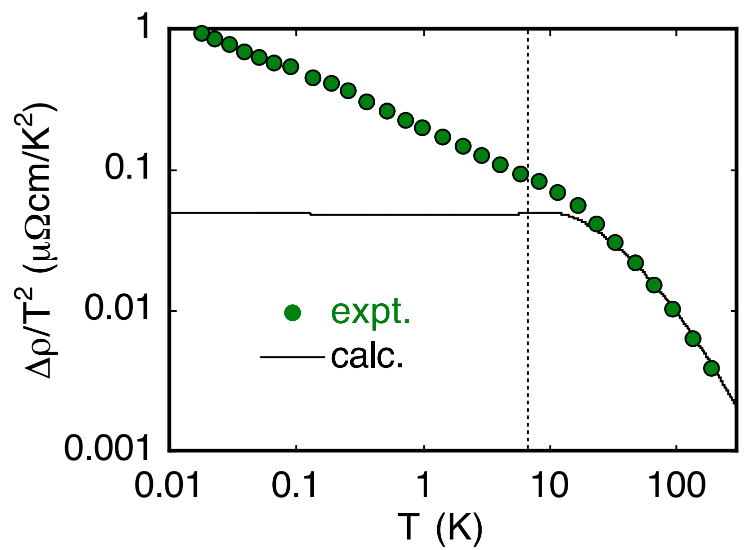


CP, McMullan, Lonzarich Physica B **199-200**, 634 (1994)
CP, McMullan, Julian, Lonzarich PRB **55**, 8330 (1997)
Thessieu, CP, Stepanov, Flouquet, JPCM **9**, 6677 (1997)
CP, Julian, Lonzarich Nature **414**, 427 (2001)
Doiron-Eyraud et al, Nature (2003)

NFL-Resistivity without Quantum Criticality







$$\rho(T) = \rho_0 + AT^\alpha + \ldots$$

↑ singular für T→0

CP, McMullan, Lonzarich Physica B **199-200**, 634 (1994)
CP, McMullan, Julian, Lonzarich PRB **55**, 8330 (1997)
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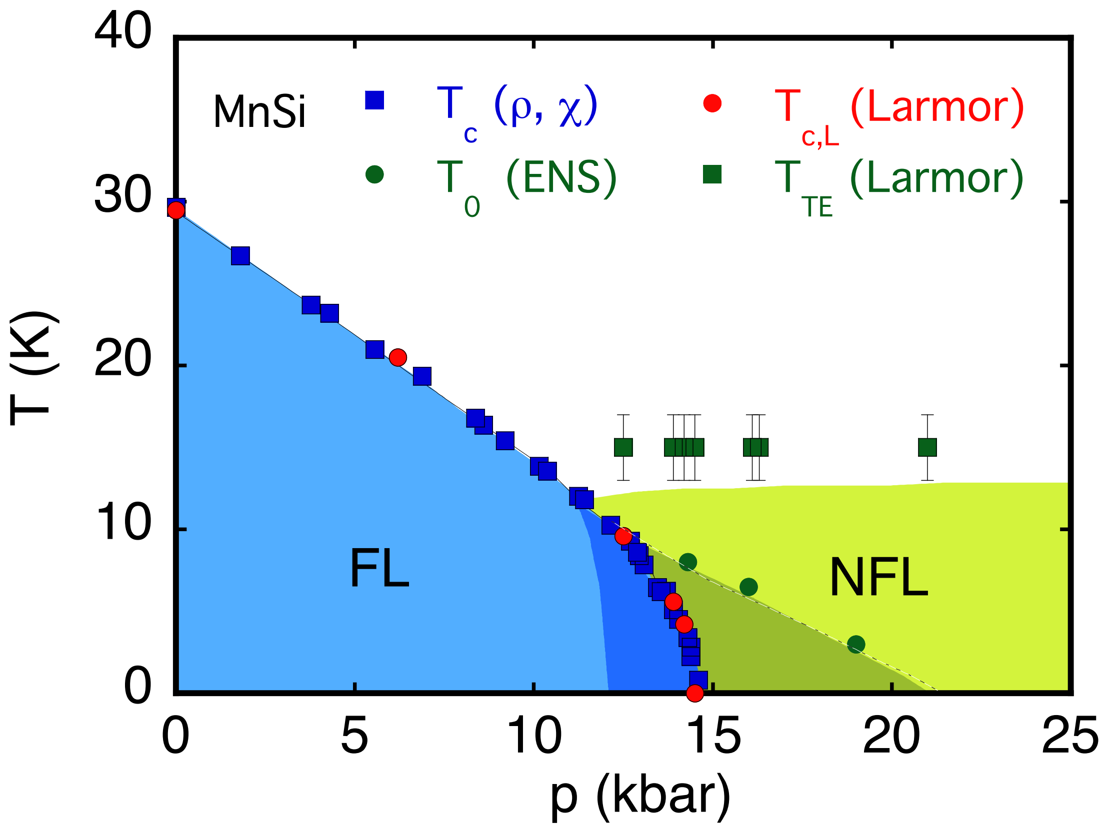
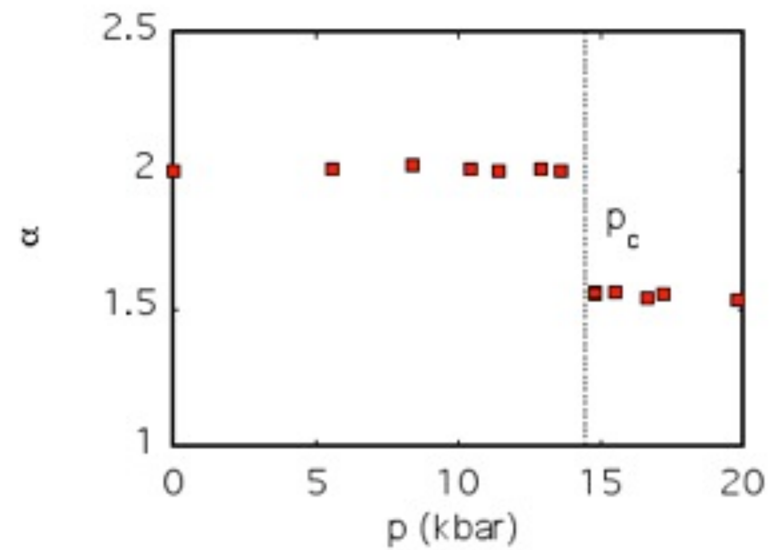
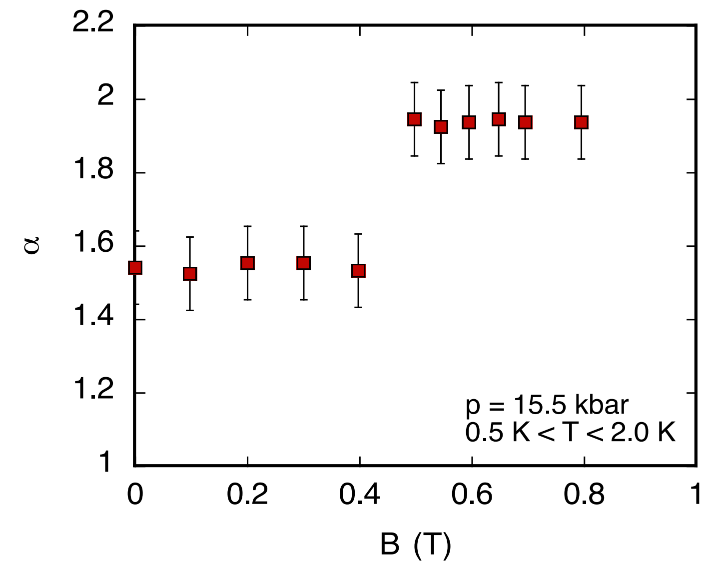
NFL-Resistivity without Quantum Criticality





$$\rho(T) = \rho_0 + AT^\alpha + \ldots$$

singular für $T \to 0$



CP, McMullan, Lonzarich Physica B **199-200**, 634 (1994)
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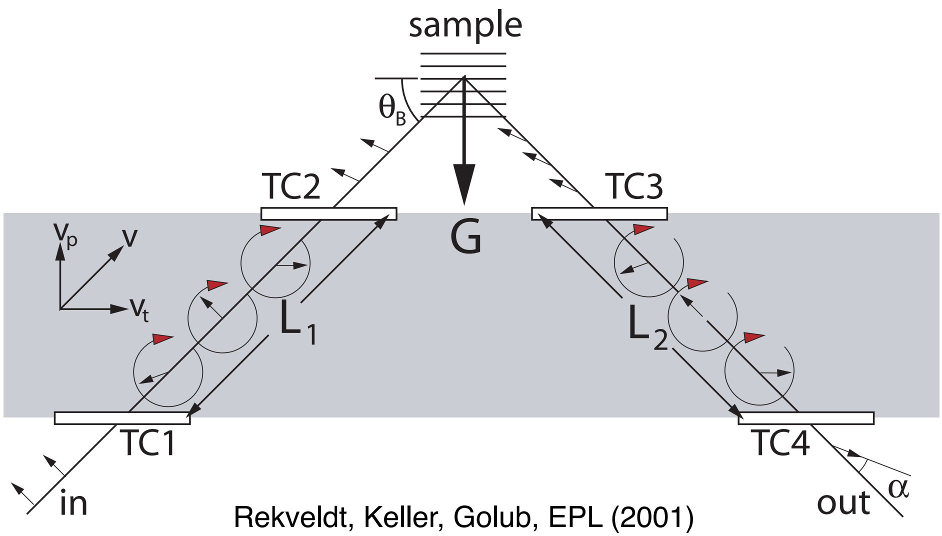
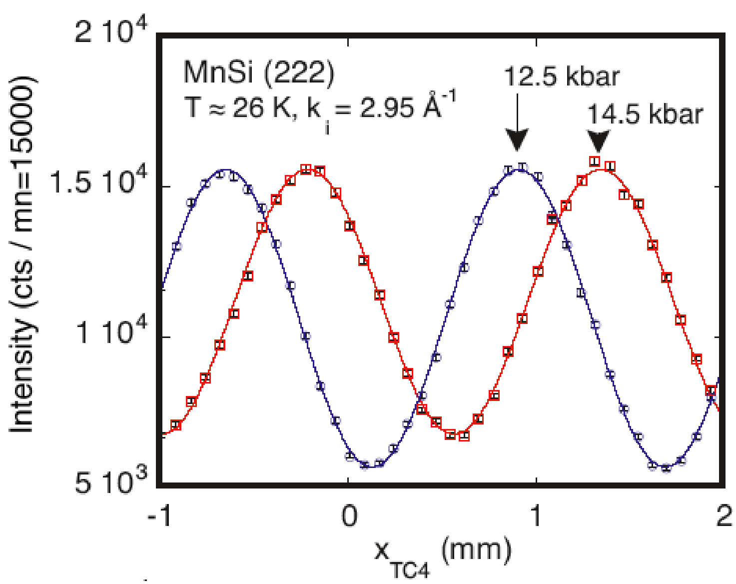
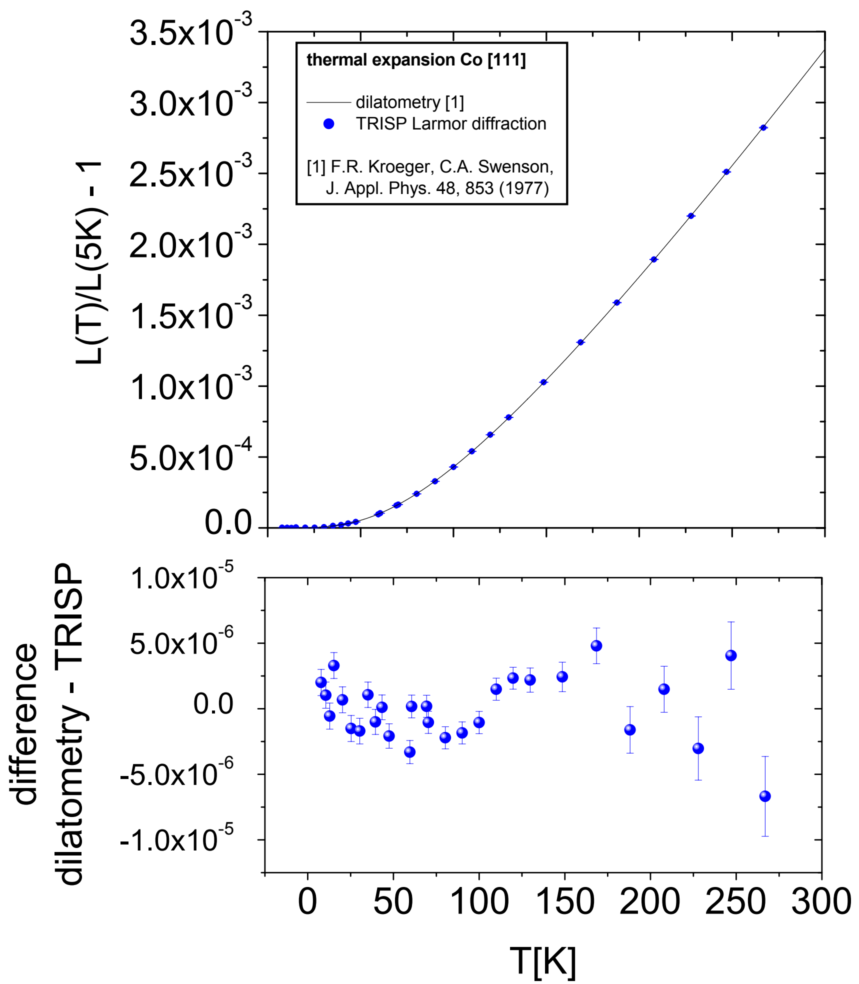
Thessieu, CP, Stepanov, Flouquet, JPCM **9**, 6677 (1997)
CP, Julian, Lonzarich Nature **414**, 427 (2001)
Doiron-Eyraud et al, Nature (2003)

Neutron Spin-Echo & Larmor Diffraction



Rekveldt, Keller, Golub, EPL (2001)

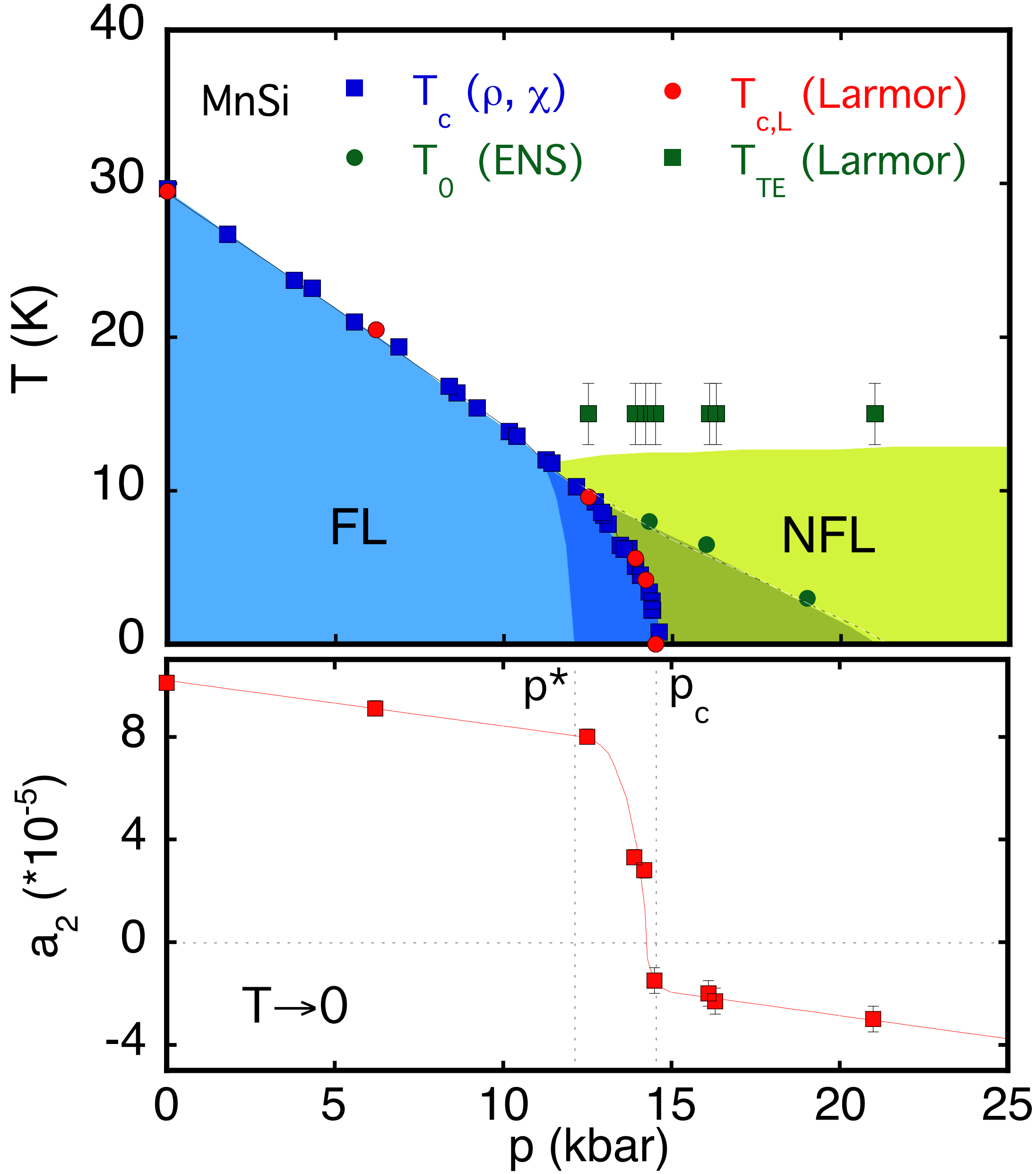


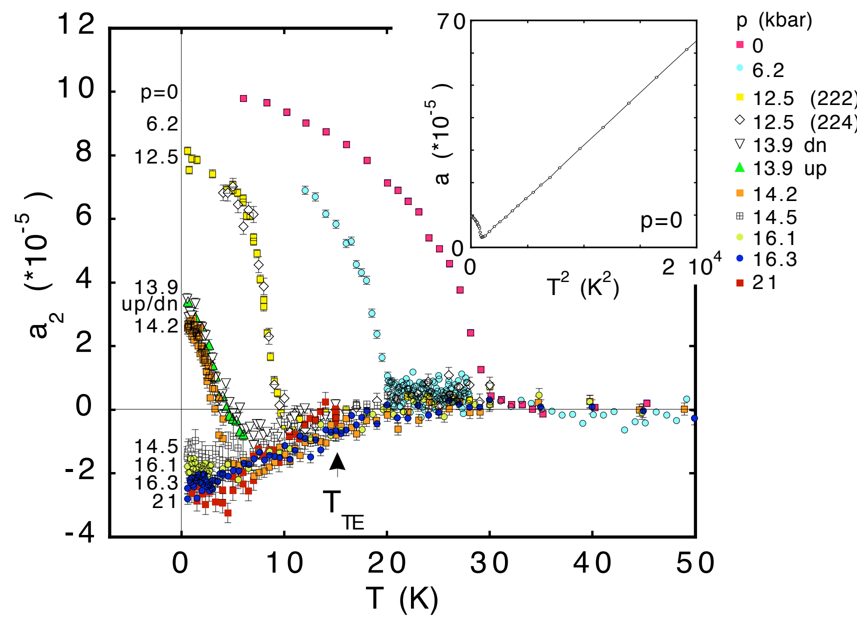


resolution 10^{-6} !!!!

measurements at TRISP (FRM II)

Non-Fermi Liquid Metal without Quantum Criticality

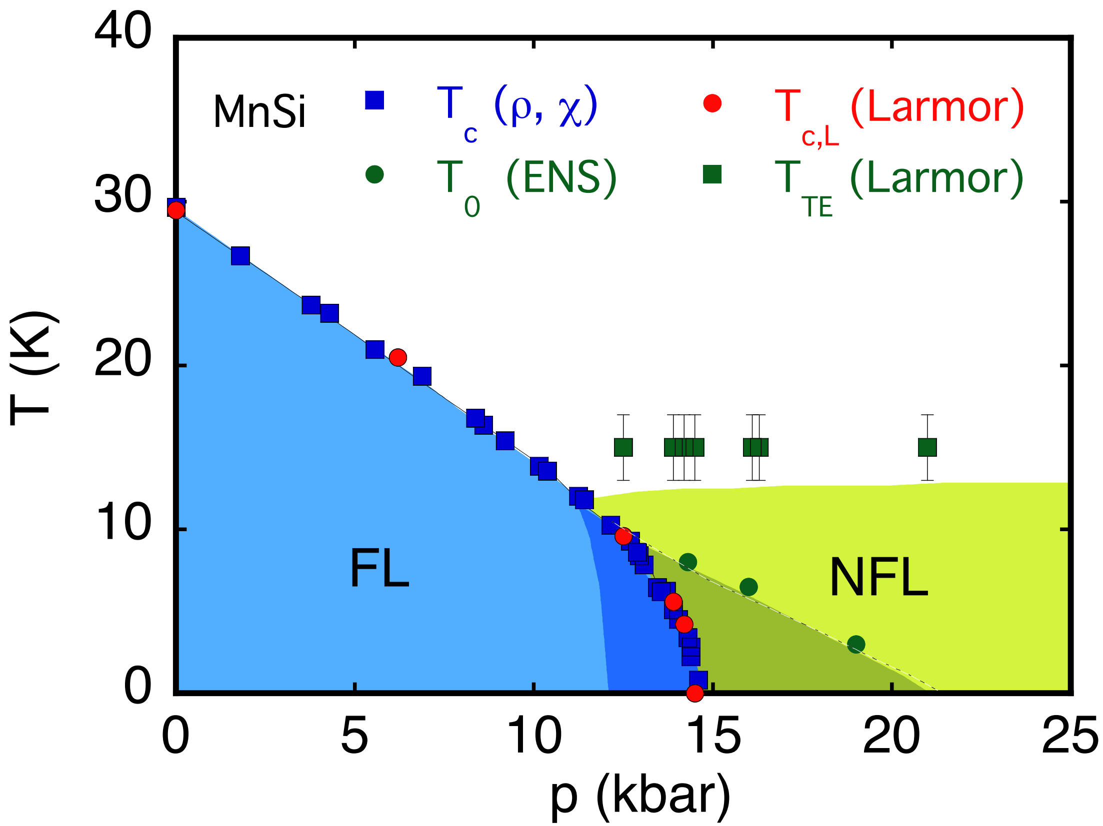


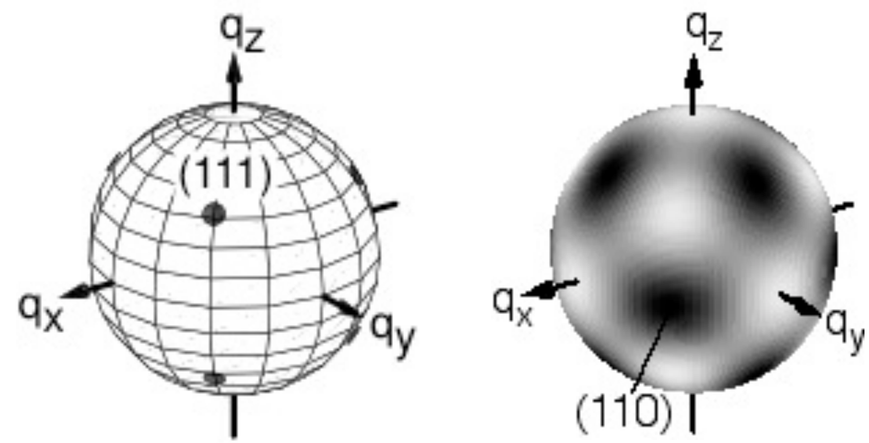


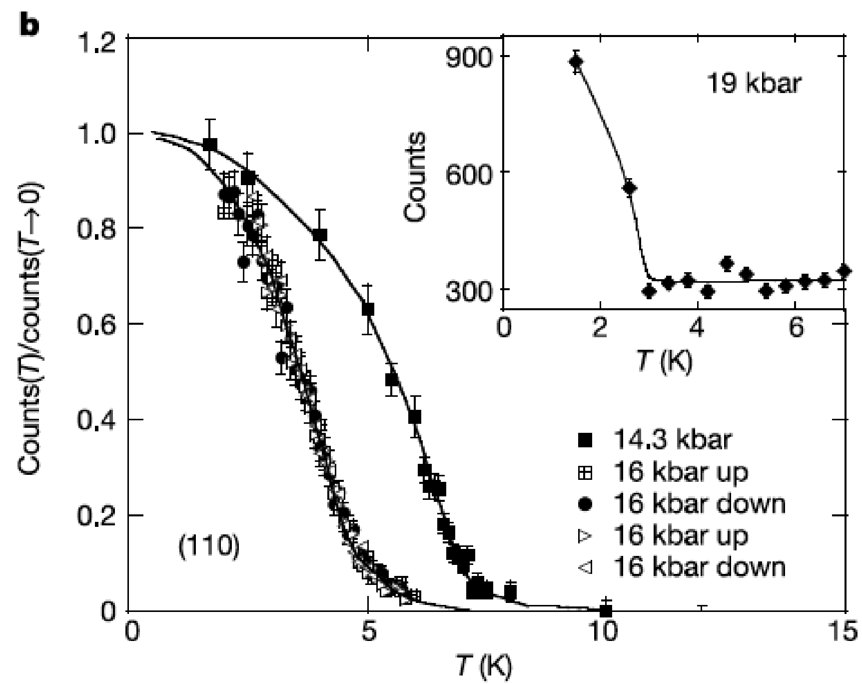
partial order above p_c:
large 'droplets'
but no expansion!!!

CP, Böni, Keller, Rößler, Rosch, Science **316**, 1871 (2007)

Partial Order in the Non-Fermi Liquid Regime

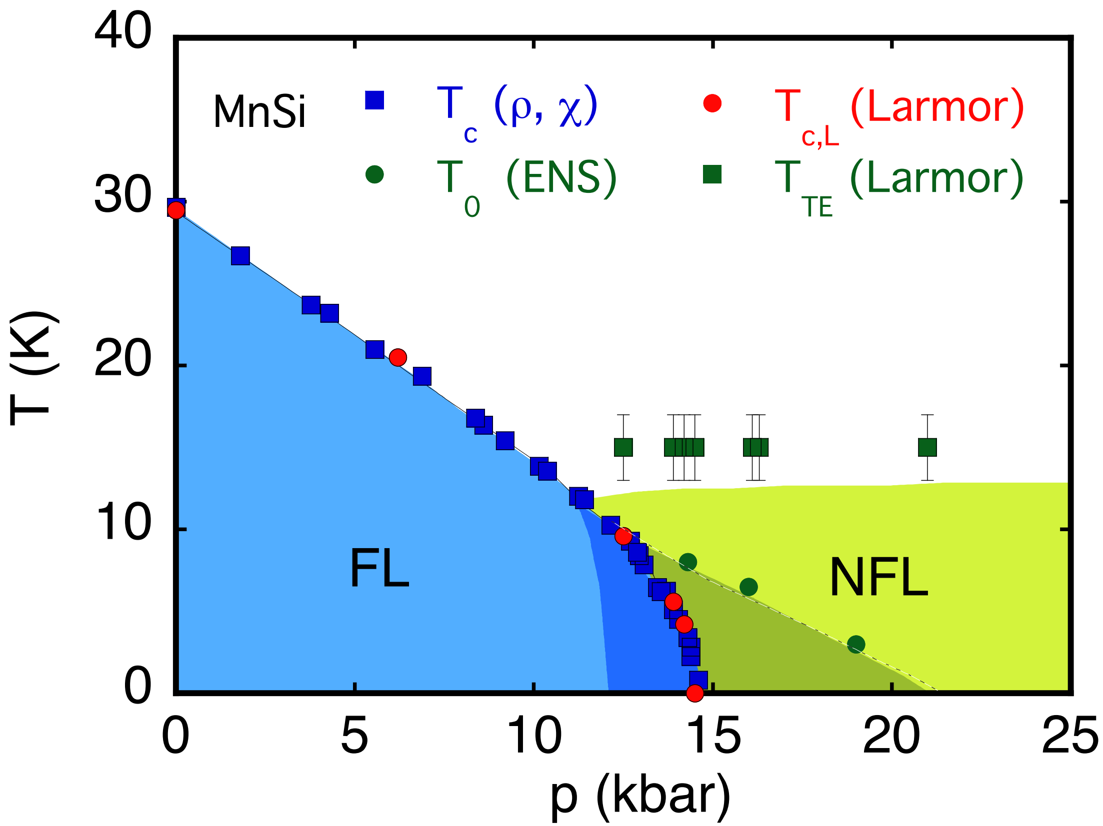


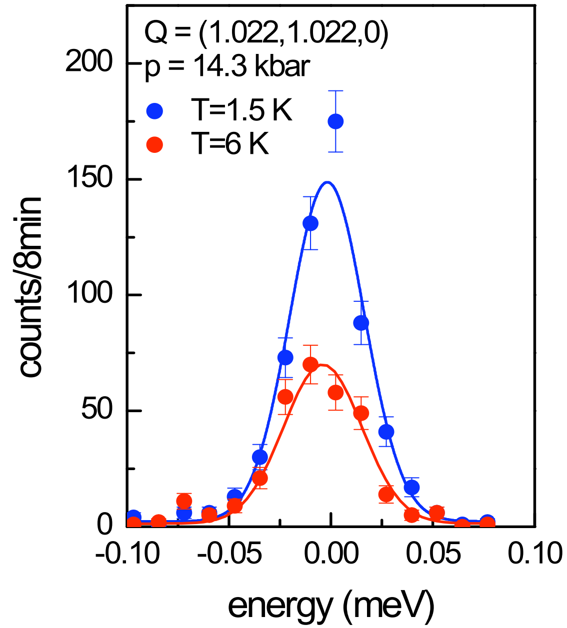


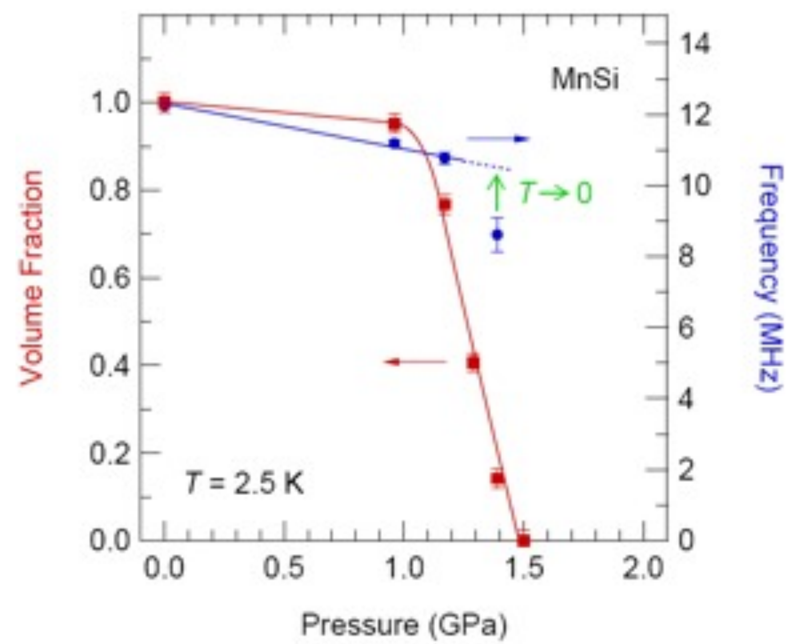


CP, Reznik, Pintschovius, v. Löhneysen, Garst, Rosch Nature **427**, 227 (2004)
CP, Reznik, Pintschovius, Haug PRL **99**, 156406 (2007)

Neutron Scattering vs mu-SR





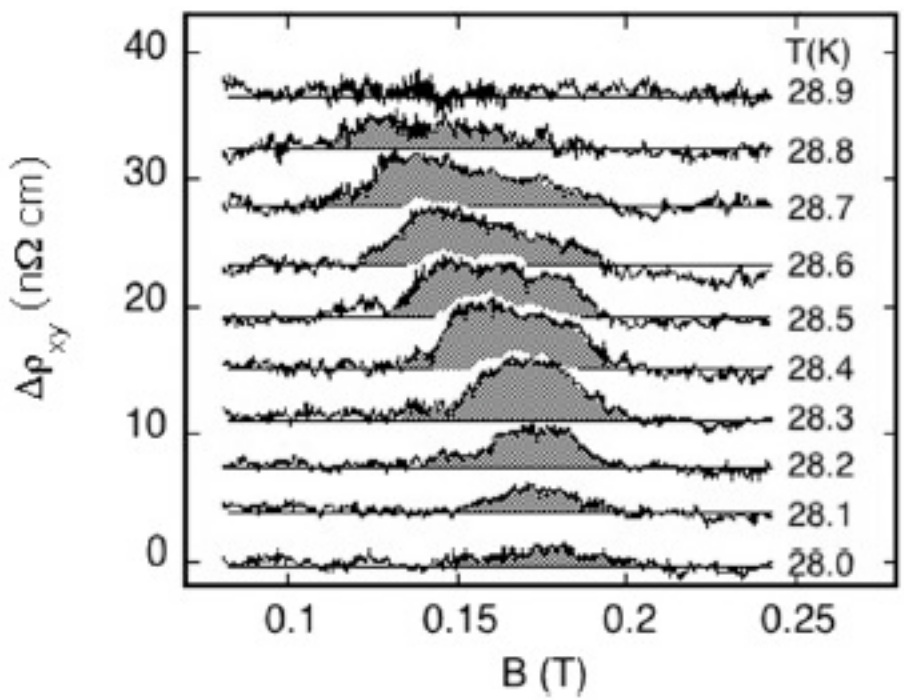


with Uemura, Nature Physics **3**, 34 (2007)

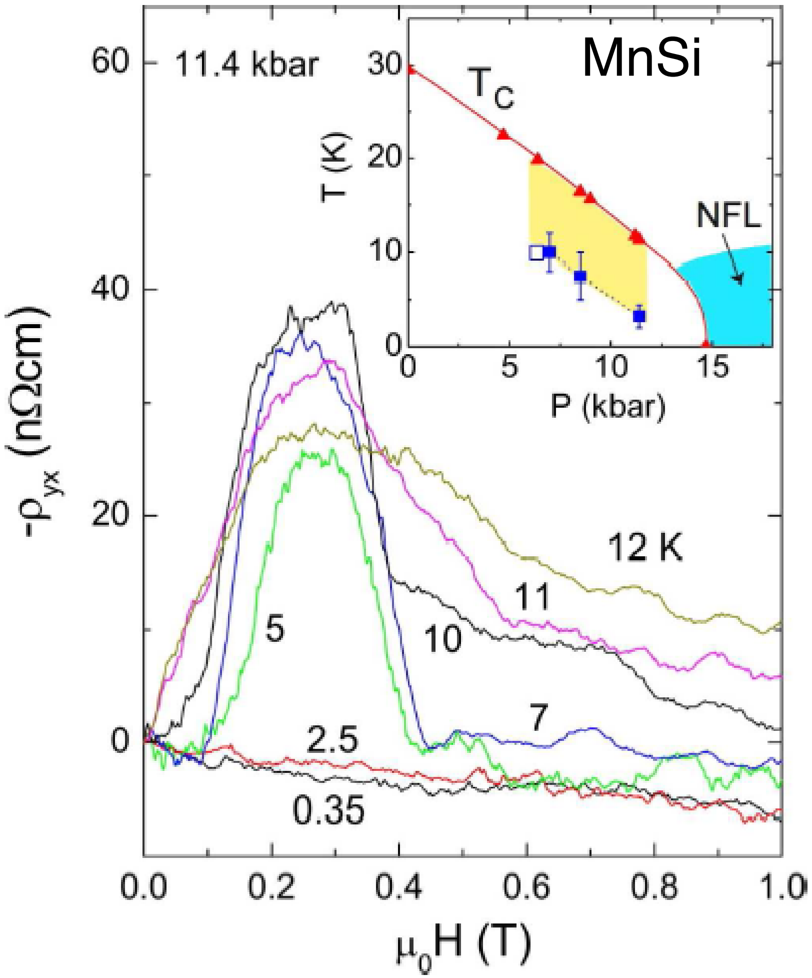
Formation of a Topological Non-Fermi Liquid (?)

Hall Effect under Pressure

Hall-Effect under Pressure (first results)

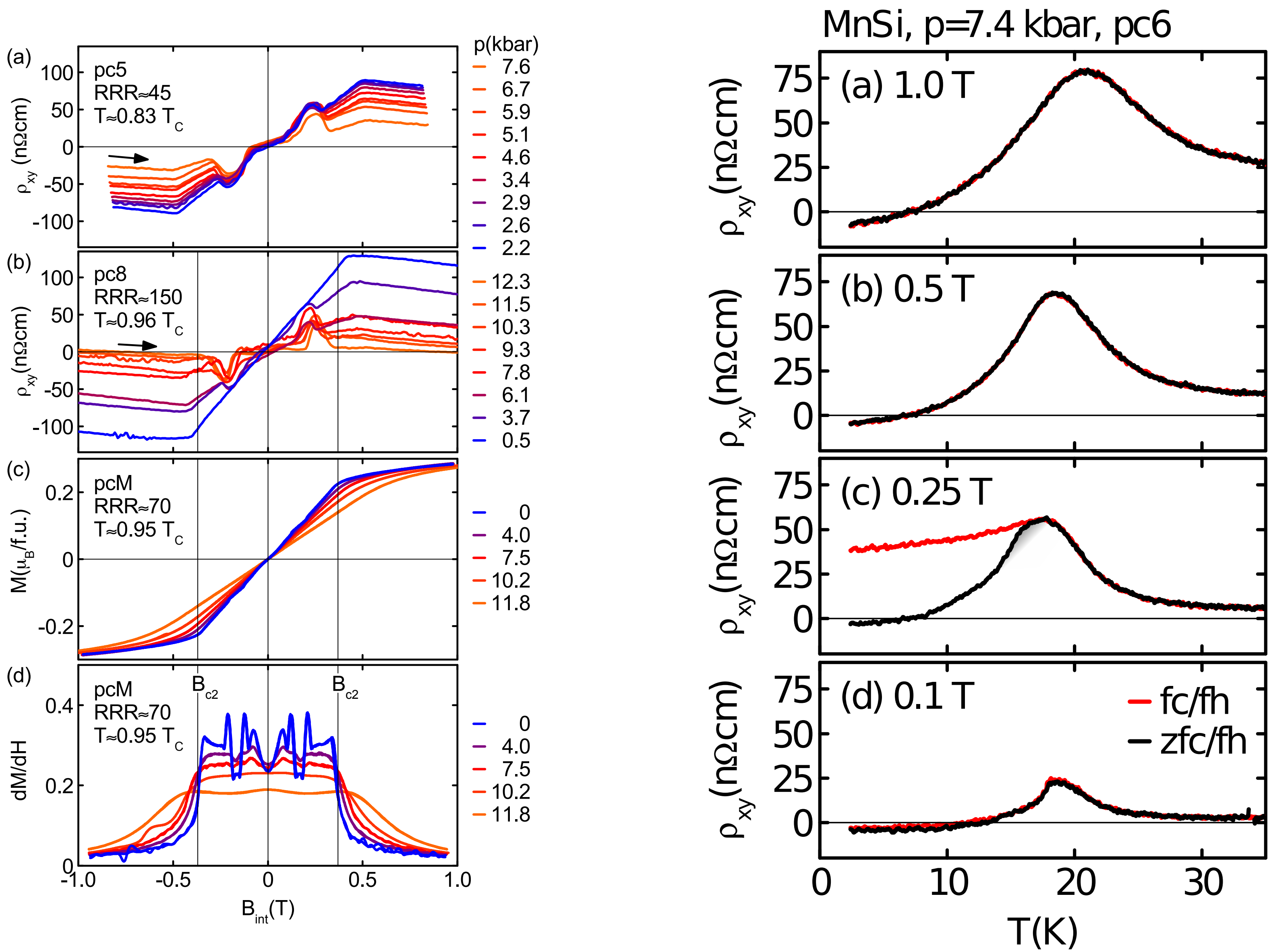


Neubauer et al., PRL **102** 186602 (2010)



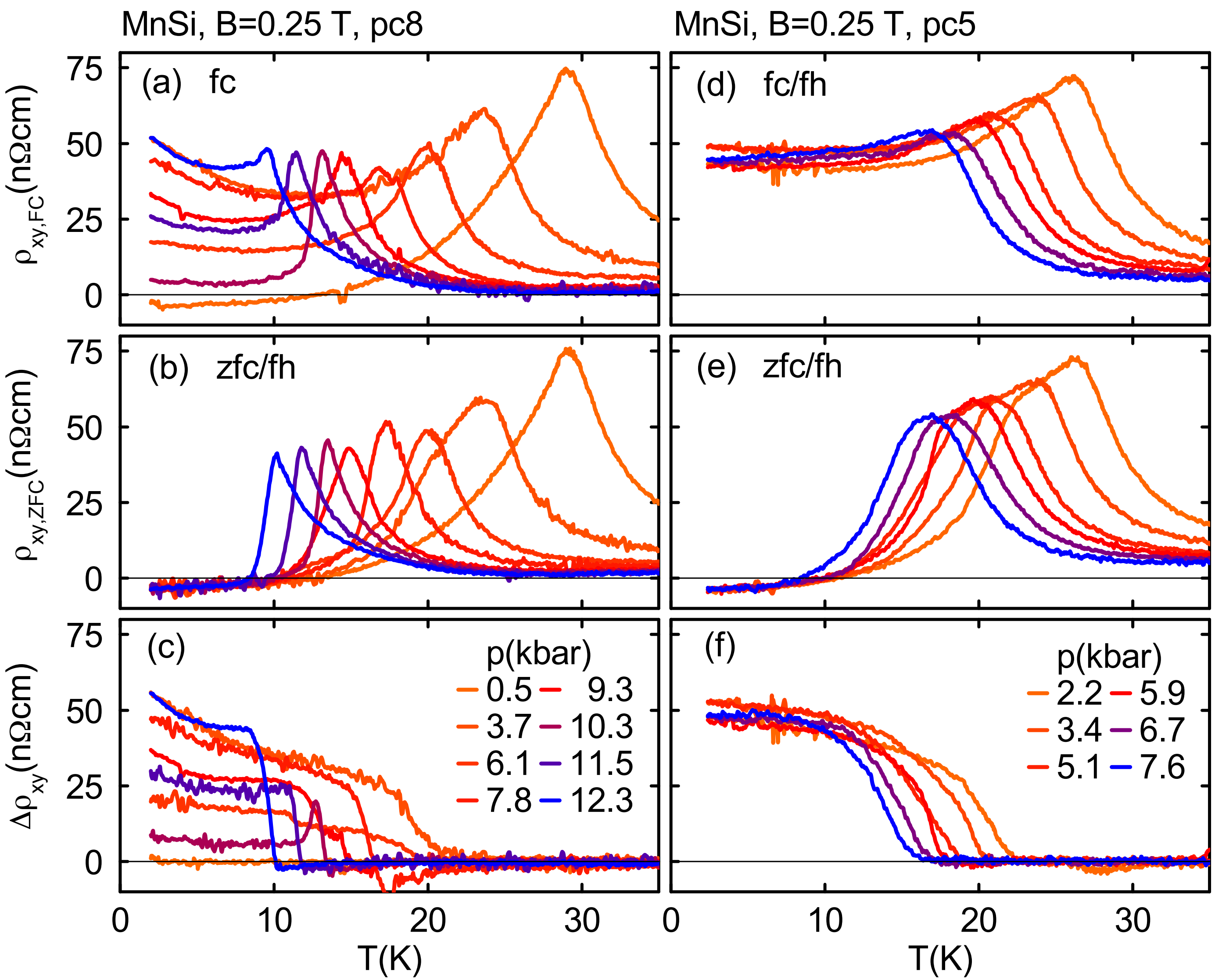
Lee et al., PRL **102** 186601 (2010)

Hall-Effect under Pressure Revisited



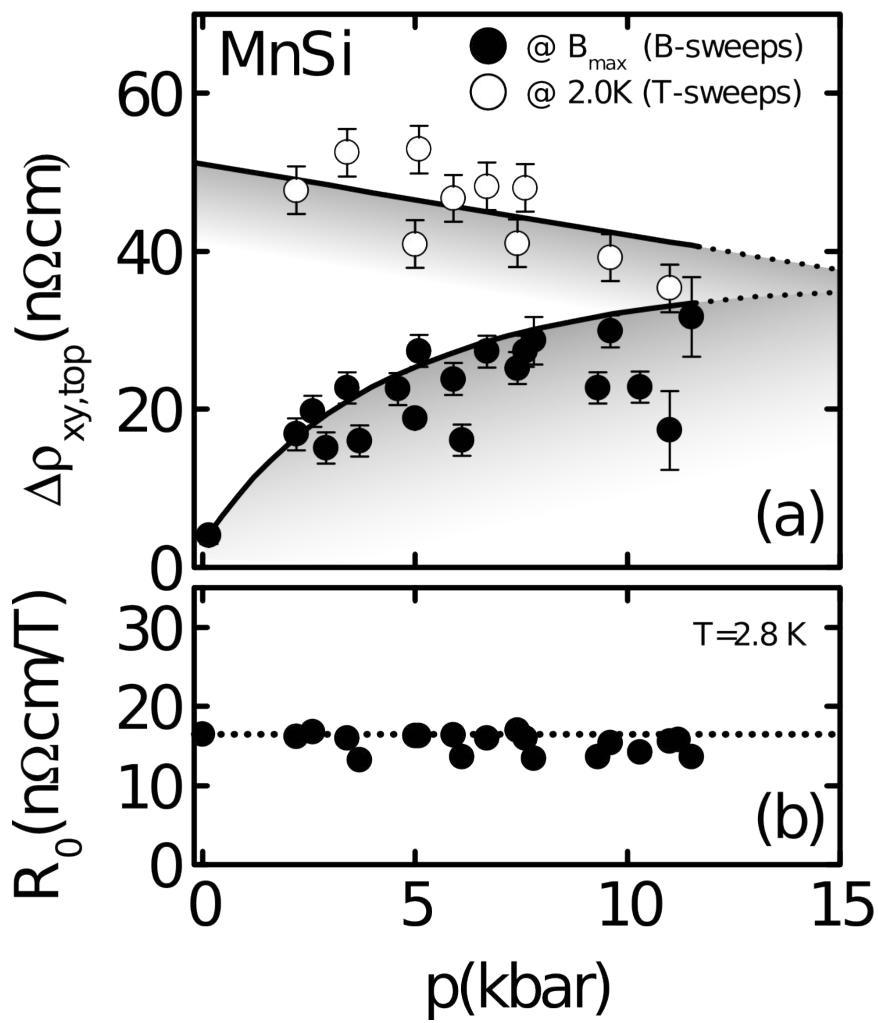
Ritz, Halder, Franz, Bauer, Wagner, Bamler, Rosch, CP PRB **87**, 134424 (2013)

Hall-Effect under Pressure Revisited



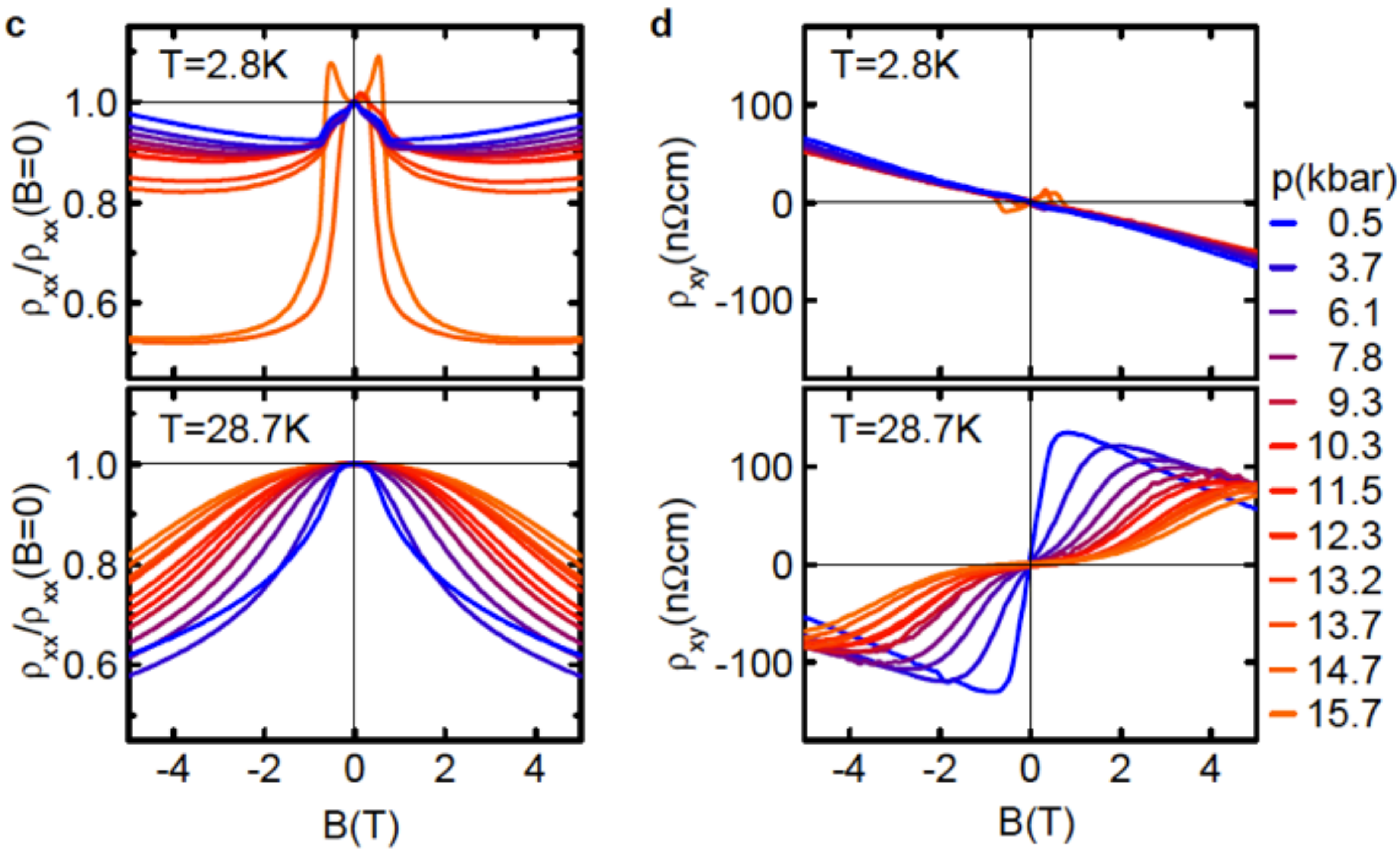
Ritz, Halder, Franz, Bauer, Wagner, Bamler, Rosch, CP PRB **87**, 134424 (2013)

Hall-Effect under Pressure Revisited



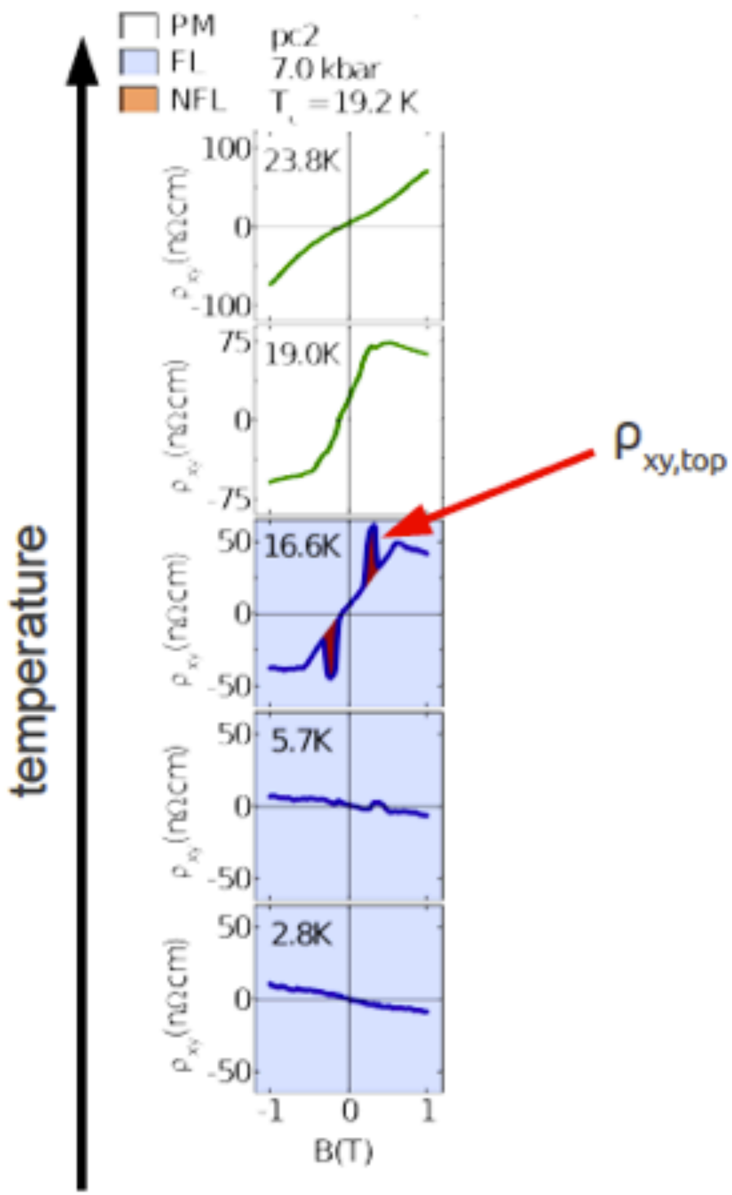
Ritz, Halder, Franz, Bauer, Wagner, Bamler, Rosch, CP PRB **87**, 134424 (2013)

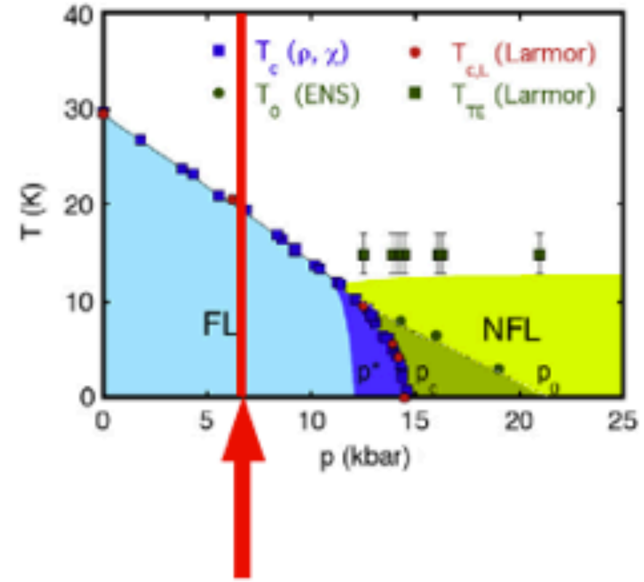
Overall-Behavior into the NFL Regime



Ritz, Halder, Franz, Bauer, Wagner, CP, Nature **497**, 231 (2013)

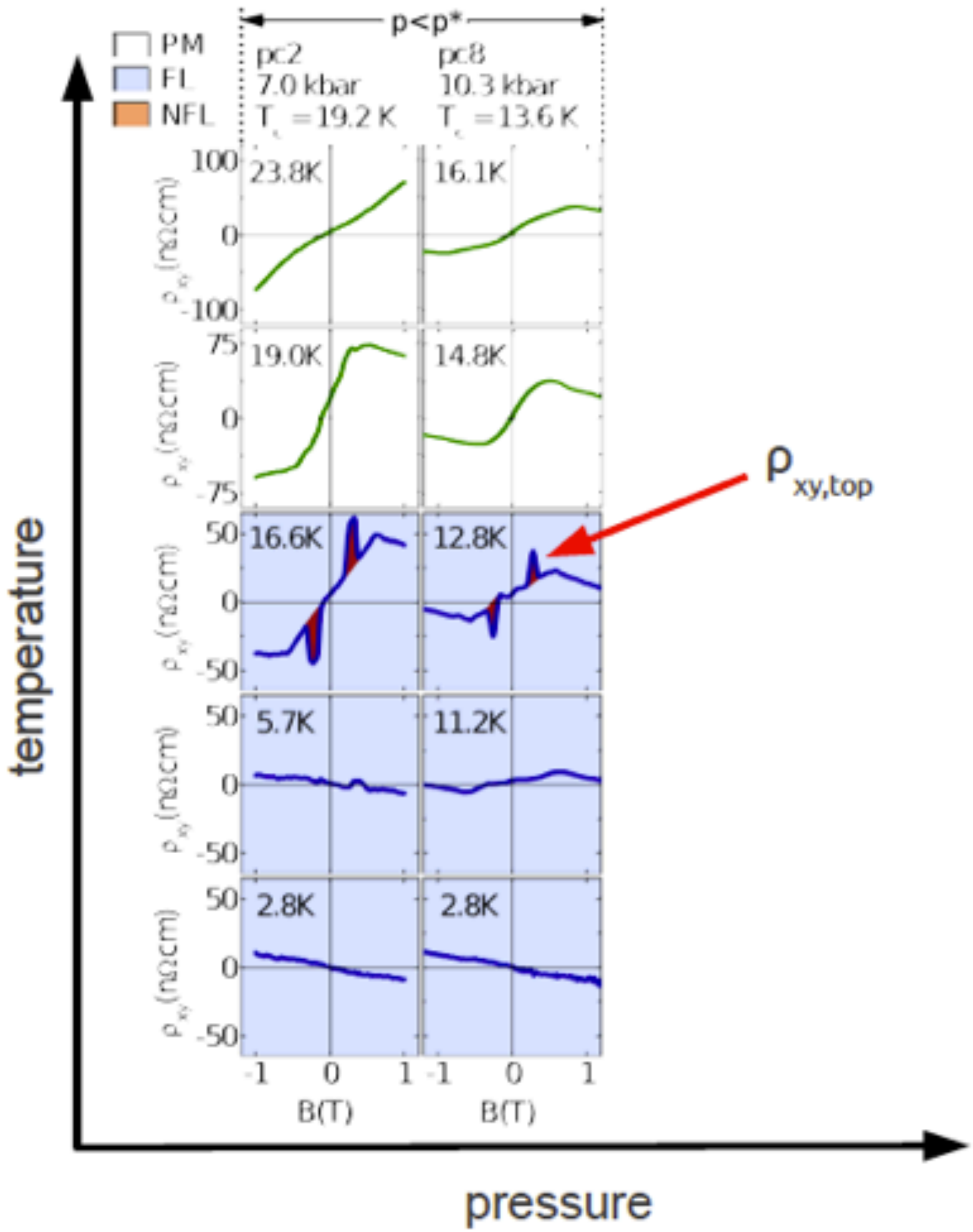
Hall-Effect in the NFL Regime

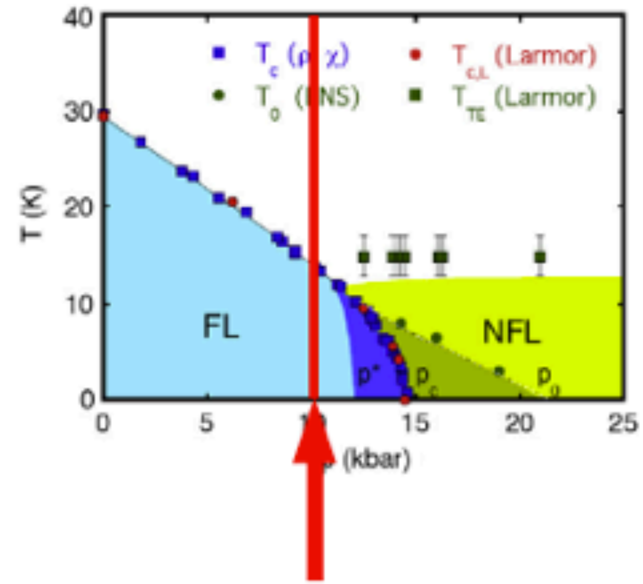




Ritz, Halder, Franz, Bauer, Wagner, CP, Nature **497**, 231 (2013)

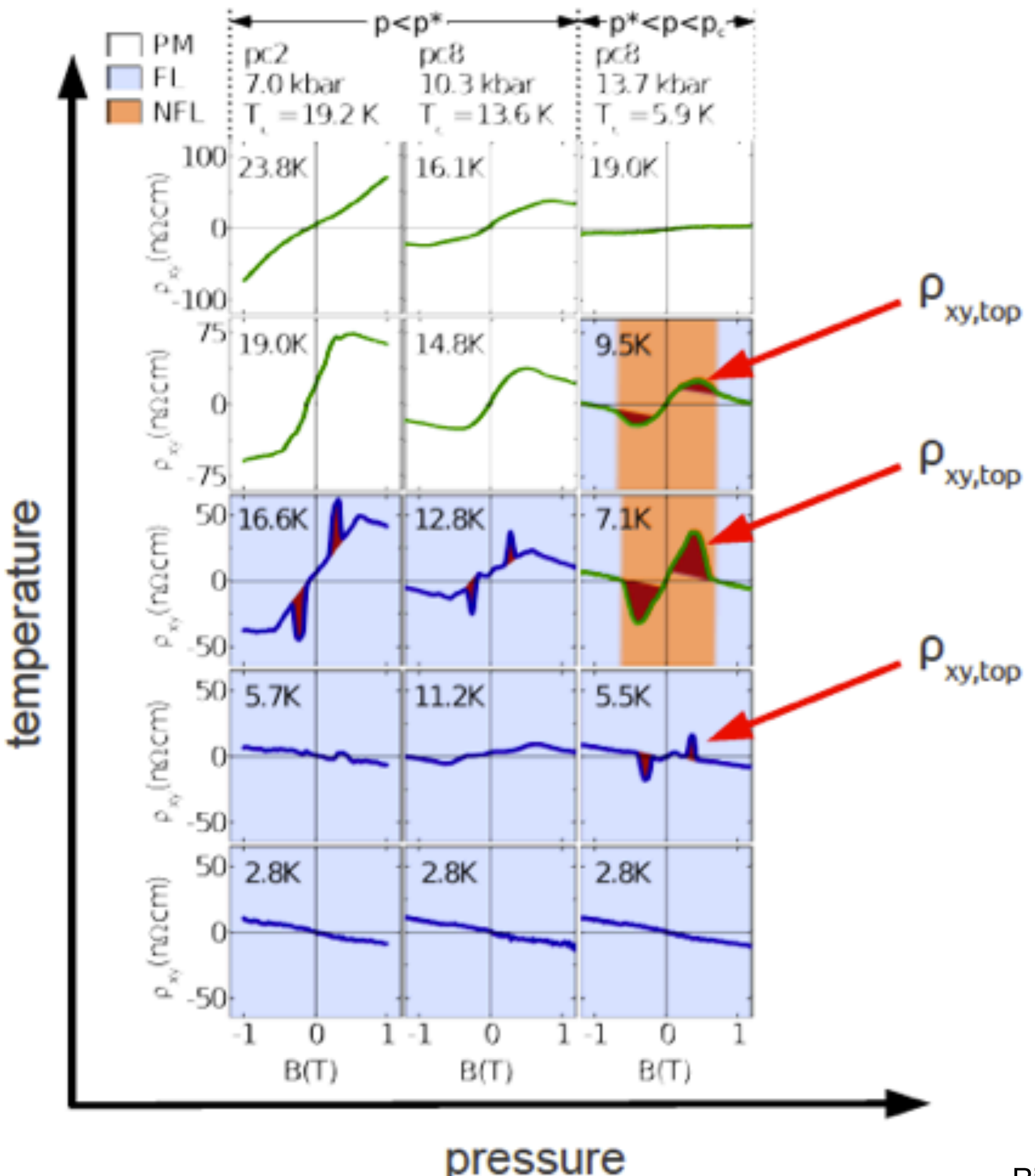
Hall-Effect in the NFL Regime

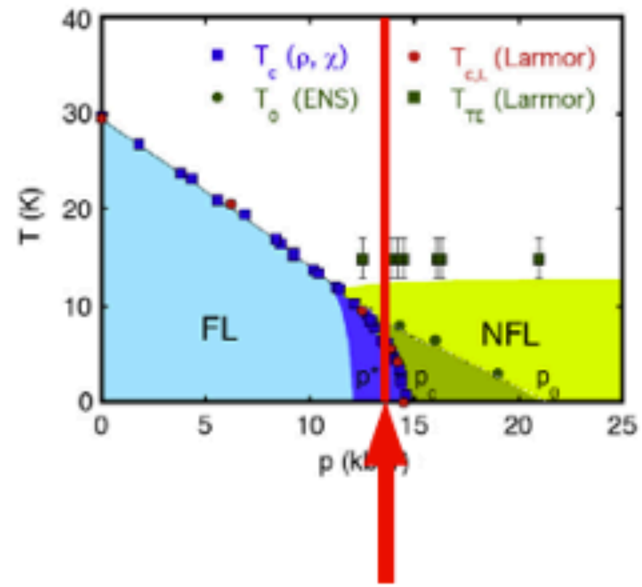




Ritz, Halder, Franz, Bauer, Wagner, CP, Nature **497**, 231 (2013)

Hall-Effect in the NFL Regime





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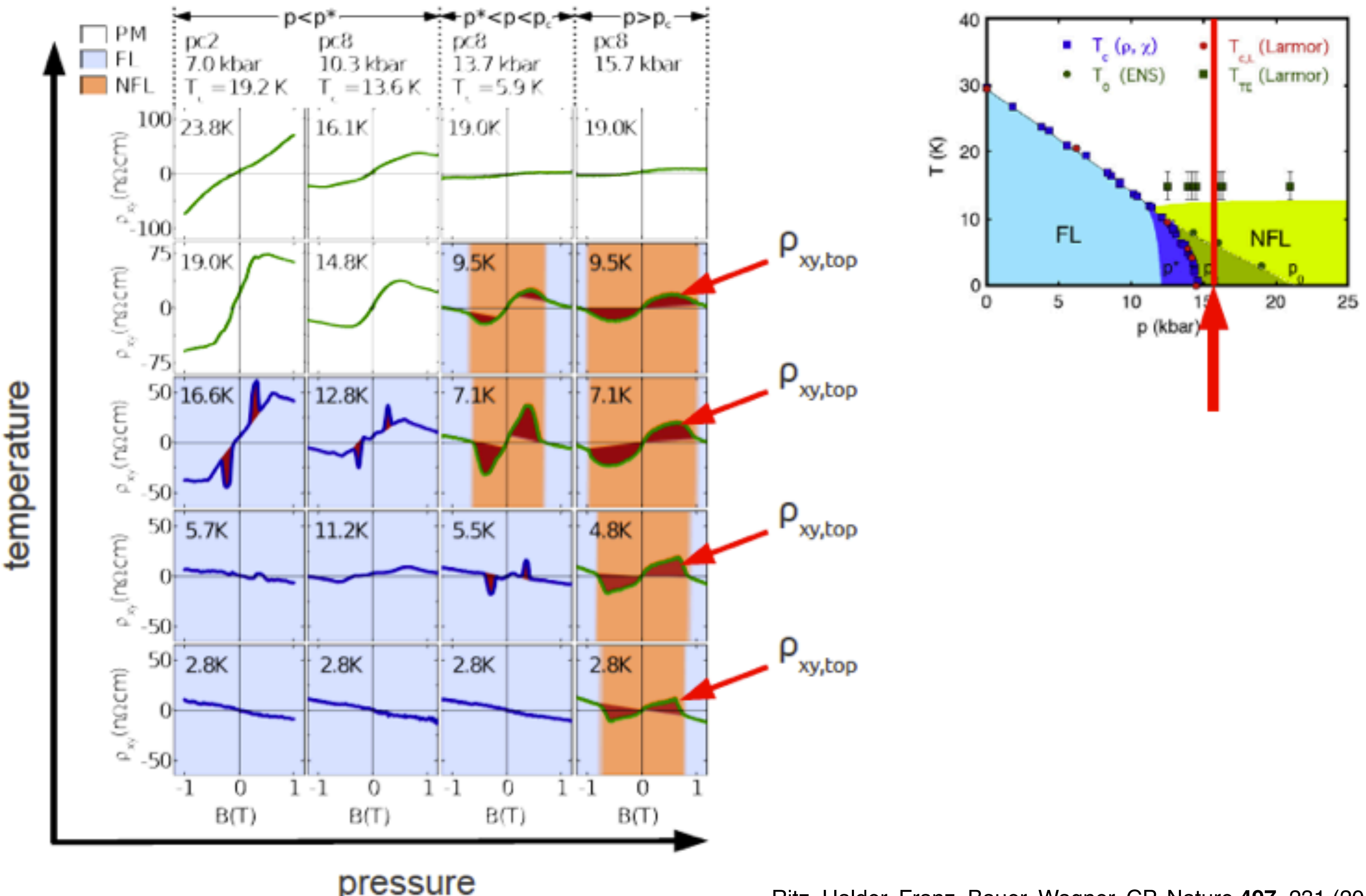

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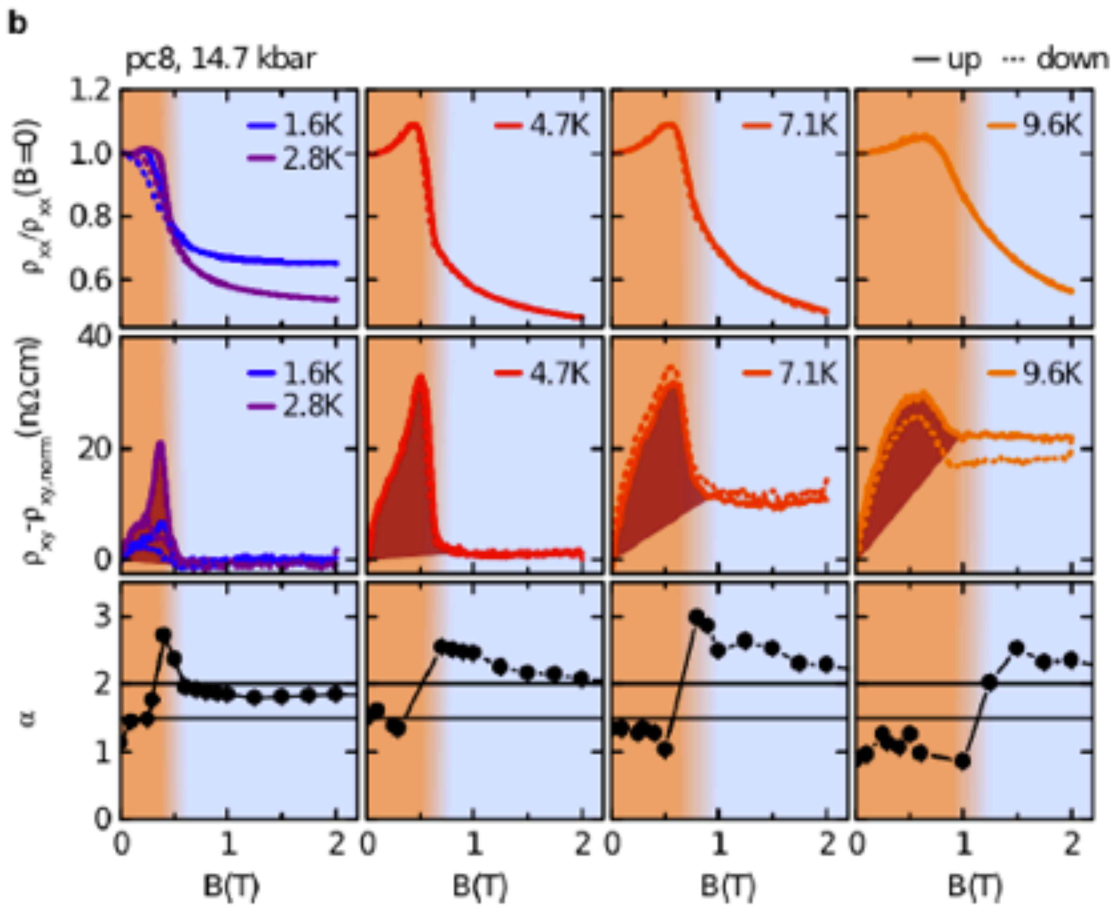
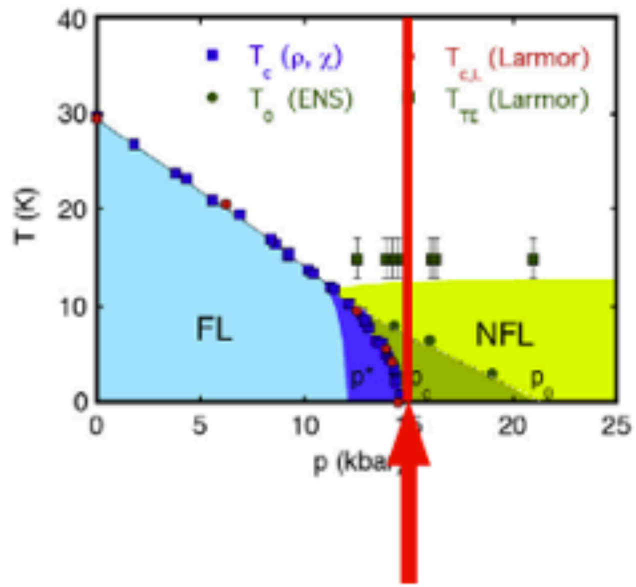
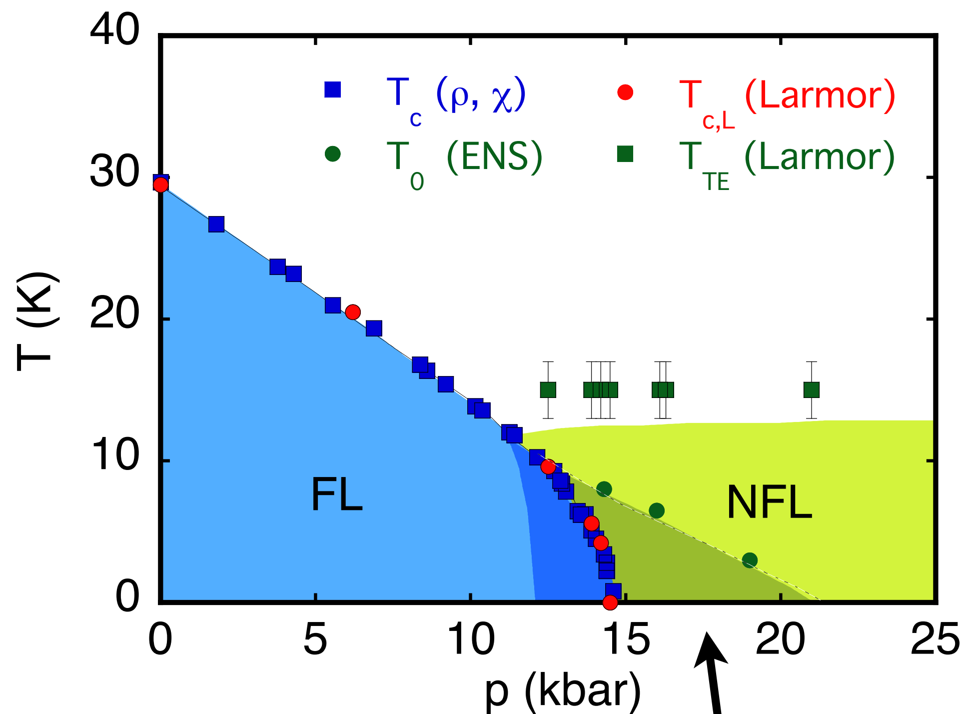
Hall-Effect in the NFL Regime

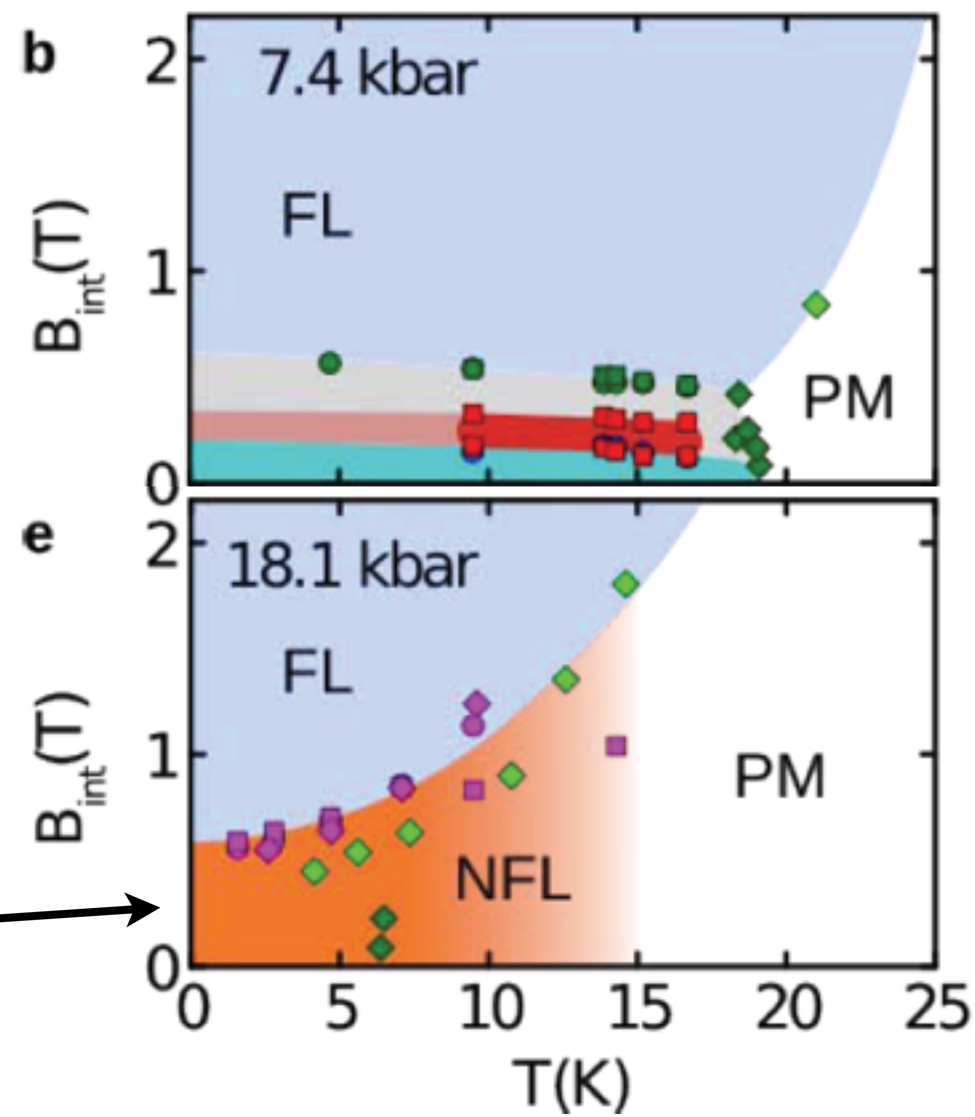




Ritz, Halder, Franz, Bauer, Wagner, CP, Nature **497**, 231 (2013)

Formation of a Topological Non-Fermi Liquid



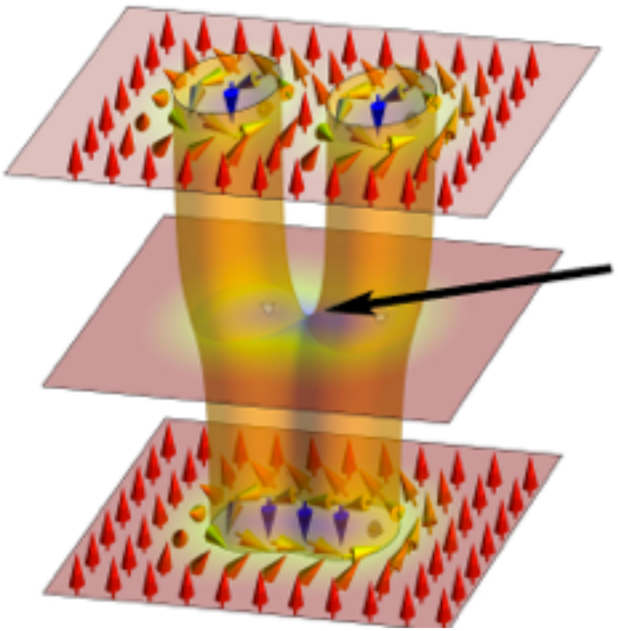


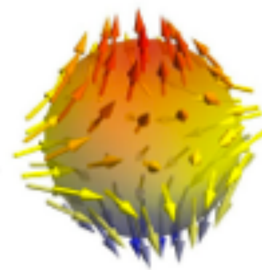
topological
Hall signal

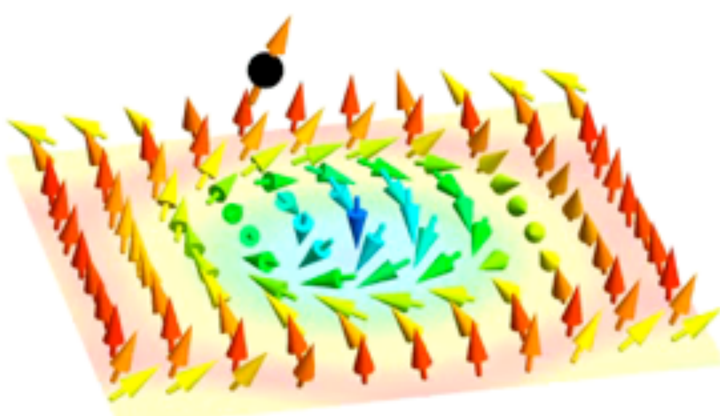
Ritz, Halder, Franz, Bauer, Wagner, CP, Nature **497**, 231 (2013)

Untold Stories

Instead of Conclusions







- emergent electrodynamics
- skyrmion flow
- ab-initio Hall effect
- inelastic neutron scattering
- polarised neutron scattering
- magnetic resonance
- Raman scattering
- routes towards skyrmions
- role of magnetic anisotropy
- uniaxial pressure tuning
- composition tuning
- elasticity moduli
- new systems
- thin films
- manipulating skyrmions
- ....